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THE POTENTIAL IMPACT OF HYPERSPECTRAL IMAGERY ON AMPHIBIOUS WARFARE PLANNING

by

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December 1999

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Military image analysts primarily use panchromatic and radar images to aid situational awareness in preparing a mission plan. Although analysts rely on these two formats, there are situations where these two sensors are unable to detect potential threats, i.e., buried mines. The Department of Defense has proposed using a hyperspectral sensor to detect threats that otherwise may not be detected by existing sensors. In order to determine the utility of hyperspectral imagery for mission planning, a task analysis was conducted at two Joint Intelligence Centers to measure image analysts' preferences to infrared, radar, panchromatic, and hyperspectral imagery during an amphibious planning process. The results showed that the image analysts were most confident using panchromatic imagery for the majority of the planning tasks; however, the analysts exhibited uncertainty for other tasks, such as detecting buried mines. Further analysis showed that image analysts could reduce their uncertainty in detecting buried mines and producing bathymetric maps by using hyperspectral imagery. Although hyperspectral imagery reduced uncertainty during mission planning, operators report that this imagery is confusing. To integrate hyperspectral imagery in mission planning, image analysts must be trained to interpret a hyperspectral scene and understand how to exploit its' spectral characteristics.

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THE POTENTIAL IMPACT OF HYPERSPECTRAL IMAGERY ON AMPHIBIOUS WARFARE PLANNING

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ABSTRACT

Military image analysts primarily use panchromatic and radar images to aid situational awareness in preparing a mission plan. Although analysts rely on these two formats, there are situations where these two sensors are unable to detect potential threats, i.e., buried mines. The Department of Defense has proposed using a hyperspectral sensor to detect threats that otherwise may not be detected by existing sensors. In order to determine the utility of hyperspectral imagery for mission planning, a task analysis was conducted at two Joint Intelligence Centers to measure image analysts' preferences to infrared, radar, panchromatic, and hyperspectral imagery during an amphibious planning process. The results showed that the image analysts were most confident using panchromatic imagery for the majority of the planning tasks; however, the analysts exhibited uncertainty for other tasks, such as detecting buried mines. Further analysis showed that image analysts could reduce their uncertainty in detecting buried mines and producing bathymetric maps by using hyperspectral imagery. Although hyperspectral imagery reduced uncertainty during mission planning, operators report that this imagery is confusing. To integrate hyperspectral imagery in mission planning, image analysts must be trained to interpret a hyperspectral scene and understand how to exploit its' spectral characteristics.

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GLOSSARY

°K	Degrees Kelvin
μm	micrometers
λ	wavelength
ARG	Amphibious Ready Group
CATF	Commander, Amphibious Task Force
CLF	Commander, Landing Force
DN	Digital Number(s)
FM	US Army Field Manual
FMFM	Fleet Marine Force Manual
GIRH	Generic Intelligence Requirements Handbook
GSD	Ground Separation Distance
IMINT	Imagery Intelligence
IPB	Intelligence Preparation of the Battlefield
IR	Infrared

IRARS	Image Resolution Assessment and Reporting Standards
IRS	Indian Resources Satellite
JIC	Joint Intelligence Center
JP	Joint Publication
HSI	Hyperspectral Imagery
LANDSAT	Land Resources Satellite
MAGTF	Marine Air-Ground Task Force
MUG	Multispectral Users Guide
MSI	Multispectral Imagery
MSIIRS	Multispectral Imagery Interpretability Rating Scale
NIIRS	National Imagery Interpretability Rating Scale
NIMA	National Imagery and Mapping Agency
PFPS	Portable Flight Planning System
SPOT	Satellite Pour d'Observation de la Terra
TM	Thematic Mapper

UAV	Unmanned Aerial Vehicle

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I. INTRODUCTION

Military planners transform doctrine, objectives, and capabilities into the commander's concept for decisive battlefield action. One of the most fundamental tasks that planners perform is to determine the relative location and possible effects of certain essential elements: mission objective, friendly capabilities, battlefield characteristics, enemy responses, and weather. The planner's measure of effectiveness is the commander's approval of a proposed plan. Planning missions for naval forces can be difficult in some situations because the objective area can be located a hemisphere away from the ship and available planning resources might be limited. In order to build the comprehensive plan that the commander will approve and execute, the planner relies on multiple sources of information. These sources might include intelligence in the form of satellite or reconnaissance imagery, historical data, reports from personnel inside the operating area, and enemy electronic signals.

If a mission planner needs information extracted from a remotely sensed image such as panchromatic, infrared, and multispectral satellite imagery (MSI), he or she will rely on the skills of the image analyst. An experienced image analyst exploits the strengths and weaknesses of each media format to gain insight about the operating area, providing valuable information that an untrained person could not. However, this process has limitations. Inaccuracy and incomplete information in these formats decrease the amount of available intelligence that can be used to portray the battlefield accurately. For example, maps may not display all relevant features. Visible (panchromatic) sensors require clear visibility during the daytime, and may not provide useful data. Infrared

sensors give information on thermal differences between objects within a scene, but are still subject to interference from clouds, and may not distinguish essential elements of information. Traditional imagery may not answer some important questions. If the analyst is fortunate, other intelligence sources are available to compensate for these problems, though with lower confidence. The image analyst or mission planner must then determine which information source is most accurate if they happen to contradict. Interpretation problems and errors create intelligence gaps that introduce uncertainty into the planning process.

For example, a military unit planning an amphibious assault is concerned with how fast friendly forces can ingress inland. Enemy defenses and soil trafficability are just two factors that may hinder this movement. Even with high image quality, the analyst may not detect well-camouflaged defenses or ascertain soil type on panchromatic imagery. However, infrared (IR) sensors can distinguish camouflage from natural vegetation and MSI can be used to classify soils. On the other hand, mission planners might mistrust information from sensors such as infrared or MSI because these formats often do not provide photograph-like images. If multiple information sources or trained interpreters are not available, there will be more intelligence gaps. The planner must still propose a concept of operation, but he or she will be less confident in the overall plan. Such a plan may result in the planner unwittingly rejecting the best available area for landing and selecting a higher risk area instead.

In most cases, the provided intelligence is adequate; however, there are situations when the available intelligence resources fail to adequately depict the battlefield.

Alternative resources should be evaluated for possible integration as operational capabilities, provided they offer the planner the intelligence necessary to gain the commander's confidence in the mission plan. The Naval Tactical Exploitation of National Capabilities (TENCAP) office is investigating hyperspectral-imaging technology (HSI) to determine if it meets the above criteria (Navy TENCAP, 1998). HSI captures spatial information about the Earth in the format of hundreds of discrete electromagnetic energy wavelength bands. Proponents of hyperspectral imaging believe that applying non-literal image interpretation methods on the HSI data set can fill some of these intelligence gaps (Jensen, 1999). Their confidence is based in part on the technology's successful commercial applications in a variety of environmental monitoring functions (Lewotsky, 1994).

The purpose of this thesis is to determine whether HSI can increase the image analyst's confidence level during image interpretation. It is hypothesized that HSI will provide unique information that other formats cannot provide and/or in areas where the analyst is currently uncertain. By integrating this information into the existing knowledge base about an area of interest, the mission planner will have a more complete battlefield picture. Therefore, a better mission plan is developed that the commander has more confidence in.

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II. AMPHIBIOUS WARFARE

The following evaluation of HSI utility is conducted in the context of Amphibious Warfare. Amphibious Warfare is the art of maneuvering military forces on a seaward flank to achieve various higher-level objectives (JP 3-02, 1992). Coalition forces designed the amphibious feint during the Gulf War in order to keep the Iraqis' attention focused partially seaward while ground forces outmaneuvered the Iraqis' forces in the deserts of Kuwait and Southern Iraq (Bernard and Trainor, 1995). In contrast, General MacArthur landed US Marines at Inchon in 1951 to open a second front against North Korean forces attacking the allies at Pusan (Gatchel, 1996).

Amphibious operations differ from conventional ground operations in a number of ways. In a conventional ground operation, the physical distance that separates opponents is relatively small, while the distance between an amphibious landing force and its enemy is typically greater than fifty miles. Also, the conventional ground commander has combat power such as infantry, tanks, artillery, and possibly aircraft on the battlefield ready to conduct the operation. One of the greatest challenges in planning amphibious operations is that the commander cannot depend on any combat power ashore to be immediately available at the start of the landing. All the combat power must be ferried from the ship to the shore in the face of a non-cooperative enemy before ground combat designed to secure the objective can commence (FMFM 3-21, 1991). Finally, the landing forces' planning elements are scattered among the ships comprising the Amphibious Ready Group (ARG). This preventive measure minimizes the complete loss

of any single element should a ship be lost or damaged. However, a side effect of this dispersal is that it complicates planning efforts and information dissemination.

The planning phase described below is the first major step in an amphibious operation. Personnel from various warfare specialties such as infantry, armor, artillery, logistics, communications, and others all have valuable roles to play in planning the amphibious operation. However, this thesis will focus on the impact that intelligence and, more specifically, imagery intelligence (IMINT) has on the planning process.

A. PLANNING APPROACH

The commander's staff cannot develop an acceptable plan until the commander receives an unambiguous estimate of the operating area and the enemy capabilities and courses of action. Initial planning estimates are produced to meet this need, thus establishing baseline knowledge about the operating area. Developing this baseline from a warship is no simple task. The commander's intelligence officer begins this task with only the information directly available aboard ship. Organic reconnaissance assets such as unmanned aerial vehicles (UAV) or aircraft must be within the tactical range of the operating area in order to commence intelligence collection. Therefore, it is quite possible that during the transit to the objective area embarked intelligence personnel are almost completely reliant on external agencies such as theater-level Joint Intelligence Centers (JIC) to keep them apprised of the enemy situation. Two estimates of concern are the Intelligence Estimate and Intelligence Preparation of the Battlefield (JP 3-02, 1992; FMFM 3-21, 1991).

1. Intelligence Estimate

The Intelligence Estimate is developed to assist the commander in preparing his situation estimate, which is needed before the mission can begin to be planned in earnest by the commander's staff. One of the functions of the intelligence estimate is to reduce the uncertainty of the physical environment. The five-part textual document first concisely reviews the assigned mission. Then it describes the Area of Operations in terms of military geography, hydrographic data, and climatic effects on friendly operations. Next, enemy military capabilities and vulnerabilities are thoroughly reviewed. Finally, the estimate concludes by integrating these individual segments into a final assessment that includes the possible enemy courses of action based on their relative probability and enemy vulnerabilities that friendly forces can exploit (FMFM 3-21, 1991).

2. Intelligence Preparation of the Battlefield (IPB)

In contrast to the intelligence estimate, IPB is a graphical method of expressing the information contained in the intelligence estimate. It is a circular approach that integrates information about the terrain, weather, enemy, and one's own mission into a comprehensive picture that allows the commander to continually evaluate enemy course of action, enemy vulnerabilities, and one's own courses of action. After defining the operating area, the process evaluates the terrain using military topographical maps and imagery. The goal of terrain evaluation is to determine how terrain affects friendly and enemy abilities to shoot, move, and communicate. Weather effects on mobility and

visibility are then integrated with terrain information. To determine what the enemy is capable of actually performing, the intelligence staff evaluates and merges threat information with terrain, weather, and doctrine. The final products from each iteration of this process are battlefield "snap shots," lists of possible targets, and commander decision points (FMFM 3-21, 1991).

3. Imagery Interpretation in Support of Amphibious Operations

Image analysts must complete several types of tasks— classification, enumeration, mensuration, and delineation —individually or in combination to support intelligence production. Classification is the assignment of objects, features, or areas to classes based on appearance. An analyst may detect, recognize, or identify objects in a scene to complete classification. When performing enumeration the analyst detects and classifies discrete items in a scene so that they may be listed or counted. Mensuration is the measurement of object dimensions either to describe an area or to aid in classification. Finally, delineation is separation of regions within a scene based on criteria that, in this case, support the basic decisions (Campbell, 1996).

The image analyst uses elements of recognition to aid in completing the tasks described above. The elements of recognition are shape, size, tone, texture, pattern shadow, site, and association. The first five self-explanatory elements highlight basic aspects of objects contained in a scene. Site and association capture secondary information by building on the first five elements (Campbell, 1996).

The image analyst and the mission planner will probably not have face-to-face contact. Therefore, the analyst must have an idea of what information the planner is interested in, in order to focus the interpretation effort towards fulfilling those needs. These pieces of information are called Essential Elements of Information, which are listed as Generic Intelligence Requirements (GIRH, 1991).

B. BASIC DECISIONS

The basic decisions are twelve fundamental decision areas that affect the amphibious operation. They are partially based on the intelligence provided in the Intelligence Estimate and the IPB. The decision points are usually made in the order listed below; however, a decision point may be suspended while waiting for more information (JP 3-02, 1992). The basic decisions are:

- select the amphibious task force (ATF) general course of action
- select ATF objectives
- determine landing force (LF) mission
- designate landing sites
- determine LF objective
- determine beachheads
- select landing areas
- formulate LF concept of operations
- select landing beaches
- select helicopter landing zones
- select fixed wing aircraft drop zones
- select d-day and h-hour

The result of the basic decisions is a task force plan. From this point, units subordinate to the task force may begin planning their operations based on the basic decisions (JP 3-02, 1992). In summary, regardless of the force size placed ashore, a logically conceived plan improves the chances of meeting the objectives set forth by the issuing commander, and planning aids are at the heart of this effort.

III. VISUAL COGNITION

Traditional imagery analysis focuses on literal processing. This differs from the general approach to analyzing spectral imagery (MSI, HSI), and it is important to understand the contrast in the two approaches. The analytic process starts with a pictorial representation of a geographic region, or scene. Next, the analyst breaks the scene into specific parts. These parts are recognizable to most individuals who view the scene, but because of their additional training and experience, analysts can provide knowledge about those parts that untrained personnel cannot. The mission planner then uses the knowledge drawn from these parts to support the mission plan.

In psychological terms, the analyst is using perception to recognize and interpret visual stimuli. Photons are the stimuli that the human visual system collects. Through a complex process, they generate a perceptual image that embodies the properties the photons carry (Howes, 1990). Matlin (1994) states that the act of perceiving visual objects combines aspects of both the stimuli and the observer's internal processes.

One approach to filtering the immense body of knowledge associated with visual cognition is the information processing approach, which focuses on the psychological processes associated with transforming the stimulus into information. Within the information processing approach, a means of differentiating the model types is to determine which of the aspects that Matlin (1994) describes, stimulus or internal processes, has more emphasis placed on them. Bottom-up models place more emphasis on the stimulus, while top-down models place more emphasis on the observer's inner processes. General descriptions and models specific to each of these methods are

reviewed in the next two subsections. Figure 1 is gun camera footage of a tank taken during Operation Allied Force, which is used to illustrate important points associated with the different approaches in the hypothetical task of tank detection (FAS, 1999).

Figure 1. Gun Camera Footage of a Tank (FAS, 1999)

A. BOTTOM-UP PROCESSING

Bottom-up processing models assert that pattern recognition activities are based solely on the nature of the incoming stimulus (Chase, 1986). The human visual system identifies properties of the stimulus and converts them into perceptual information that then makes contact with processes and structures in memory (Howes, 1990). Template, feature and computational theories are all examples of bottom-up processing models. In general, bottom-up theories would assume that imagery interpretation activities associated with tank detection are based solely on the analyst's ability to identify stimuli associated with tanks that are present in the scene.

1. Template Theory

Template-based theories assume that pattern recognition activities match the stimulus to specific object templates in memory (Chase, 1986). Templates in memory are based on objects that have already been encountered. Each template captures unique shape, size, and orientation details for a unique object. A new template is created if any of those characteristics differ from existing templates. Objects are recognized when an exact match occurs between stimulus and template (Matlin, 1994). An analyst in the example posed would examine the scene looking for stimuli that exactly matches a "tank template."

While these theories work well for explaining how simple, standardized objects in uncluttered scenes are identified, template theories are unable to explain how humans pattern recognize objects in complex environments (Howes, 1990). Exact template matching to unprocessed sensory input implies that an infinite number of templates for each type of tank are stored in memory because the initial size and orientation are unknown. As stated, template theories falsely assert that an analyst could not classify a tank if only part of the tank is seen. Even with processing necessary to standardize the input before matching, an infinite number of standardized templates would be required for all the possible objects a human could encounter visually (Chase, 1986).

2. Feature Theory

Feature theory differs from template theory in that it focuses on analyzing and representing sensory information in primitive information units called features vice

templates (Chase, 1986; Matlin, 1990). This theory bypasses the problems associated with template theory because object identification and discrimination between objects occurs through the comparison and contrast of distinctive features (Matlin, 1994). Tanks can be detected in feature theory because tanks have two treads and a turret that the analyst can identify.

The major problem with feature theory is that it does not address the arrangement of features (Howes, 1990). An analyst who detects two treads and one turret by feature theory has detected a tank. However, if the turret is not centered between the treads, then they have detected something other than a tank. Feature theory makes no accommodation for this problem.

3. Computational Theory

Computational theories attempt to describe computer-based activities that replicate cognitive tasks that humans perform. The major computational model is a multi-stage model that begins with a two-dimensional array of numbers that correspond to the incoming photons' intensity (Matlin, 1994). Numerical operations on the array during each stage involve different and increasingly complex computations to convert the array into primitive units by edge detection, then two-dimensional surfaces, and finally three-dimensional objects that are compared to memory (Matlin, 1994). Computational theory is incomplete at the final levels because the transition from two- or three-dimensional surfaces to the final level of perceptual data is not well understood. Later work uses this theory to provide the basis for three-dimensional feature detection theories

(Matlin, 1994). In computation theory, tank identification occurs because an analyst is able to first identify the tank's edges and, through increasingly complex computations on the visual field, build two-dimensional and then three-dimensional surfaces that lead to the tank identification.

B. TOP-DOWN PROCESSING

Top-down processing differs from bottom-up processing in that it accounts for factors that are not present in the physical stimulus, such as the higher-level processes brought to bear in perception. Top-down processing makes it possible to identify distorted, ambiguous, and missing stimuli that reduce reaction times for pattern recognition. Context and knowledge are considered major influences in top-down processing (Howes, 1990).

1. Context Effects

Context provides expectations concerning the nature of stimuli that surround a target of interest (Howes, 1990). The observer processes the least ambiguous information in a scene first, because it provides clues toward classifying the ambiguous stimuli (Matlin, 1994). If the analyst is conducting a wide area search for tanks, context can help focus the search in two different ways. First, it helps eliminate areas from the search space. For example, tanks cannot operate in certain terrain types, so the analyst does not need to look in this terrain for tanks. Second, it points the analyst toward particular areas

by using other intelligence sources. The advantage that context provides is that it prevents the analyst from having to search the entire scene for tanks.

In remote sensor image interpretation, understanding context is particularly important because the raw information provided by the sensor can be in a dramatically different format than that usually experienced by humans. Air- or space-borne sensors collect their data from an overhead perspective. In addition, they can exploit electromagnetic radiation outside the region that the human eye senses (Campbell, 1996). However, the analyst understands what characteristics the remote sensor captures and uses that information to aid in interpretation. In a daytime infrared image, a tank will probably be warmer than the surrounding environment, so the analyst might focus on the brighter sections of a scene for tank characteristics.

2. Knowledge Effects

Knowledge gives the analyst familiarity with the objects in a scene (Matlin, 1994). One form of general knowledge that humans use unconsciously is perceptual constancy. This is a higher-order capacity that stabilizes the environment's appearance across different domains even though the retinal image is continually changing. From this stable environment, it is then possible to detect and identify objects. Shape, size, and color are three domains in which perceptual constancy operates (Matlin, 1994; Sekuler, 1994). In a tank search, the analyst is able to identify a tank from almost any aspect because of shape-constancy. Similarly, if the analyst zooms in on a portion of a scene and sees a tank, he or she knows from size constancy that the tank's physical size did not

actually change. Finally, displaying images in gray scale bypasses the need to establish or maintain color-constancy. This is done in part because some sensors such as infrared and radar collect their data outside the range of the human eye. Therefore, using color in this instance can confuse the analyst because the information conveyed by color does not have an equivalent in real life.

Trained experts can also use subject matter expertise to organize information in ways that facilitate its storage and retrieval (Chase, 1986). Military image analysts have specialized knowledge about both the remote sensor and an enemy in a particular geographic location (Campbell, 1996). If the analyst knows that an armor division is deployed to a region, they can apply knowledge about both the order of battle and troop disposition to the task of finding tanks.

3. Stages Model

The primary model that psychologists use to explain top-down processing is the stages model (Neisser, 1967), which is a discrete, sequential model for visual information processing. The lower-level analyses or preattentive processes rapidly test the visual field for simple target characteristics such as color, shape, and orientation in parallel (Neisser, 1967; Chase, 1986; Matlin, 1994). The preattentive mechanisms automatically register features. Targets that are discernable by simple criteria will appear to "pop out" of a scene no matter how many items are in the display (Chase, 1986; Matlin, 1994). The higher-level or focal attentive processing occurs when cognitive resources are applied to just a portion of the visual field (Chase, 1986). Focal attentive processes can use the

features registered in the preattentive phase to perform operations including grouping, target identification based on multiple criteria, and confirming a target's absence (Chase, 1986). Ultimately, focal attentive processes take advantage of context and knowledge to build an appropriate object that may be compared with the existing knowledge base in memory in order to make a judgment (Neisser, 1967).

Later elaboration of the stages model includes setting a threshold value for identification of given stimuli (Howes, 1990). This is significant because only partial processing is required before making a judgment call. In this case, an analyst would only need to see part of a camouflaged tank to detect it.

C. COGNITIVE MAPS

After the analyst has processed a scene, the task is not yet complete; something must be done with the analysis. In military applications, for example, the location information accompanying the processed information is as important as the detected objects. The analyst builds internal abstract diagrams called cognitive maps to represent the result of that interpretation (Chase, 1986). Storage and processing errors are two issues associated with cognitive maps.

1. Storage

The method of storing data affects how quickly it can be used. Two such methods are hierarchical storage and route-based storage. Hierarchical storage does not attempt to describe the spatial relationships between all the objects in a scene, but rather describes

and stores relationships by subregion. Relationships between subregions are then stored, and so on up the hierarchy (Chase, 1986). A military example of this hierarchical storage involves the display and representation of ground units. On a small-scale (large area) map, perhaps only higher-level military units are of interest, so only unit strengths greater than a brigade are plotted. However, the brigade's alignment in the maneuver space is based on functions such as movement, offense, or defense. This function determines how the smaller-sized units (regiments, battalions, etc.) that comprise the brigade are located in this area. This hierarchical relationship can exist on a sliding scale for the ground units.

Route-based storage involves organizing the movement as a series of connected vectors. Significant information is then stored relative to the route vector (Chase, 1986). A military example of this type of storage is a pilot's flight plan. The pilot completes a mission by flying the aircraft along a series of connected points (flight path). Along the flight path, the pilot completes certain actions that are related to his mission, and thus stores information such as enemy units, using the flight path as means of ordering data.

2. Errors

There are usually errors associated with information encoding and application, because of the abstract nature of information storage. Alignment errors describe difference in displacement between the stored and actual locations of spatial information. The direction of the error usually tends toward a cardinal reference point. Internally

stored information that is stored in an absolute reference frame is of lesser value until it is rotated toward the user's reference frame (Chase, 1986).

The analysis conducted below suggests that the top-down model for visual cognition is the better model for the interpretation process as observed in this study because much of the knowledge that the analyst uses cannot be explained in a purely bottom-up paradigm.

IV. PLANNING AIDS

The intelligence estimate can convey a large amount of information about the operating area. The planner will also use pictorial representations of the operating area such as topographical maps and remotely sensed images in conjunction with the intelligence estimate to plan the mission. The two types of planning aids, textual documents and pictures, together have a synergistic effect because the planner uses the image as a way to manipulate knowledge in memory (Chase, 1986).

The formats most commonly used by planners and interpreters are topographical maps, black and white images that contain information from a single spectral band, and possibly color images containing information about two or more spectral bands. This section describes each of these formats and characterizes the strengths associated with the format–how well it describes the operating area — and its challenges or limitations in interpretation. The level of detail contained in the format descriptions provides the reader with an understanding of how the analyst interprets the data presented. Part of the challenge described later is how to integrate MSI/HSI into the planning process and the product, the packet.

The final product of the intelligence production process is a packet that is delivered to the amphibious force. Such packets generally are composed of maps and small image chips for targets and areas of interest. Should the force be called on to plan a mission, they will commence preparation with these products. While certain multispectral images have been included in these packages in the past, hyperspectral data

have not, and one of the challenges of this thesis is to determine how to integrate this information into the package.

A. MAPS

Image analysts and planners both use maps to orient themselves to the area of interest. The map scales primarily used in planning are topographic (1:50,000) and Joint Operations Graphics (1:250,000). These scales represent the best balance between coverage and specificity (FM 21-26, 1993). Maps are the primary medium that planners use to prepare missions because in many instances the map provides the planner most of the information necessary to plan and execute a mission. Analysts also use maps, but they use the map more as reference material, such as comparing the features in an image to the map or vice versa or for plotting the approximate location of a target of interest.

Military topographical maps are graphical representations of a portion of the Earth's surface. Map-making starts with a mathematical model to chart the surface as viewed from above. The model ensures that the spatial displacement between objects is accurate relative to geo-coordinates within a given specification for a particular scale. Additional data is added to the map based on the information contained in aerial or satellite photographs and ground surveys (Gervais, 1999). Ground features are represented using standardized colors, symbols, and labels. Figures 2 and 3 as well as Table 1 provide examples of how each type of data is encoded. Only static information is printed on a map, since revision typically does not occur more often than once every several years. Therefore, the placement of dynamic targets such as mobile troop

positions would be irrelevant due to the long time lag between map development and use (FM 21-26, 1993; AFSC1N151, 1995). The chart's legend provides example symbols on an uncluttered background with a concise textual description of the symbol's meaning, such as the one provided in Figure 3. However, elevation and background coloring are two areas where information encoding is not straightforward.

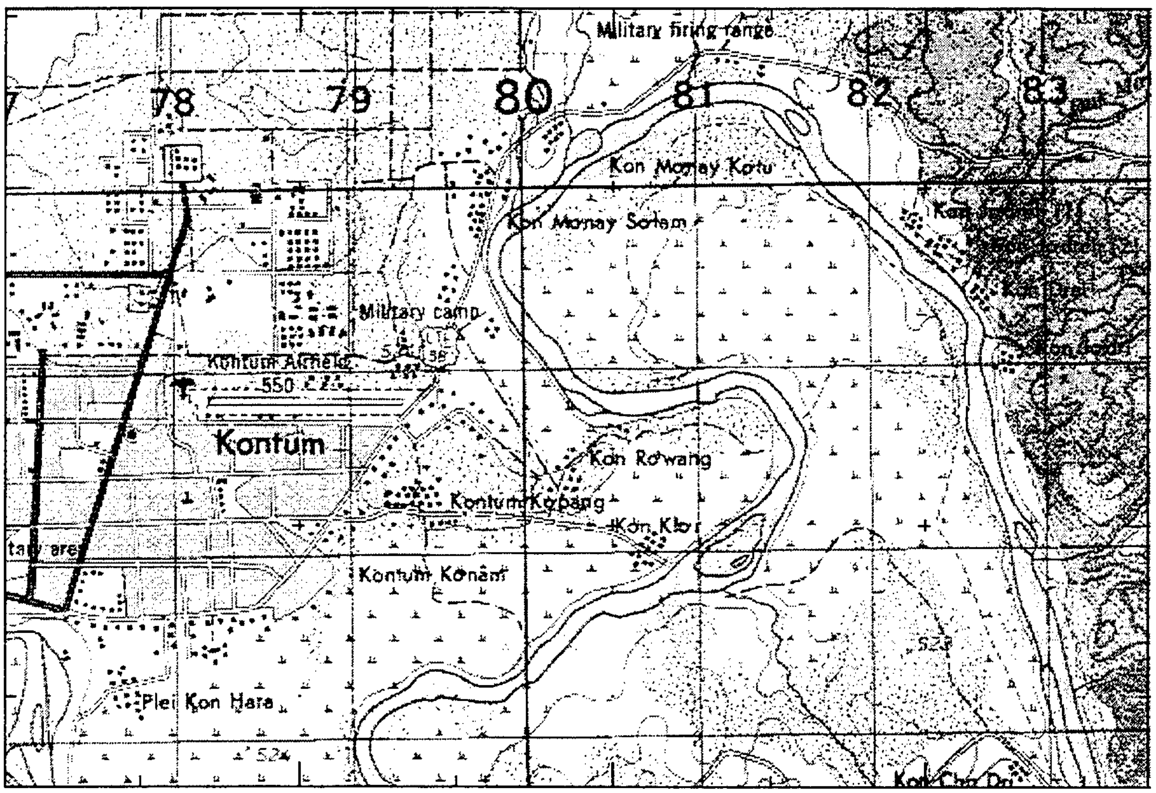


Figure 2. 1:50,000 Topographical Map of Kontum, Vietnam (NIMA, 1995)

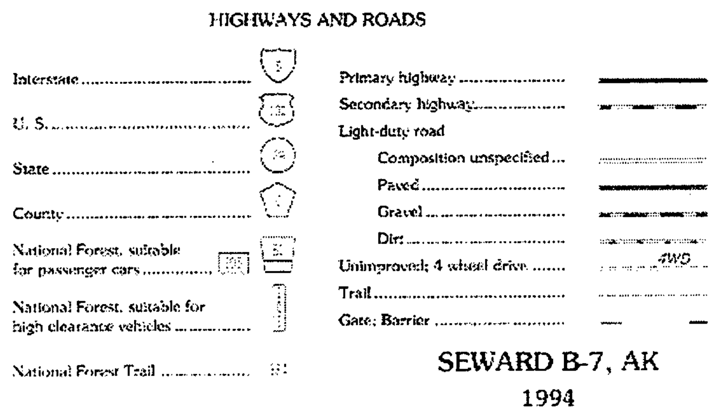


Figure 3. Legend Examples (US Department of the Interior, 1994)

Color	Meaning
black	man-made cultural features (roads, buildings, surveyed elevation spots)
red-brown	natural cultural features, relief features, non-surveyed spot elevations
blue	hydrographic data, lakes, swamps, rivers, and drainage
green	vegetation of military significance
brown	relief features and elevation on older maps
red	cultural features, populated areas, main roads, and boundaries
purple	information related to safety of flight

Table 1. Military Map Color Coding Schemes (FM 21-26, 1993)

1. Elevation

The use of contour lines is the most common method for displaying elevation on a map. A contour line connects a series of points that are at the same elevation. The line also describes the terrain's shape at a particular elevation. Contour lines are drawn based on a standard change in elevation that varies with map scale. Terrain features are more precisely described by adding more contour lines to the map. Numerical values printed

occasionally near a contour line provide the reader a reference elevation to calculate other elevations. Enclosed contour lines that are inside other enclosed lines are of a higher elevation. Relative spacing between lines depicts the surface gradient; shallower gradients have more space between line pairs (FM 21-26, 1993; AFSC1N151, 1995). Figure 4 shows examples of contour lines for different terrain features.

Elevation data is also available in a digital form called Digital Terrain Elevation Data (DTED). DTED is a matrix of terrain elevation values for a region of the world, defined by one-degree square cells. There are different levels of DTED quality. For example, a DTED Level 0 cell has 1000-meter lateral separation between matrix values. Additional software such as NIMAMUSE are required to read and display DTED data (NIMA, 1998). Table 2 summarizes the accuracy levels for DTED Levels 0 through 5 (FAS, 1997).

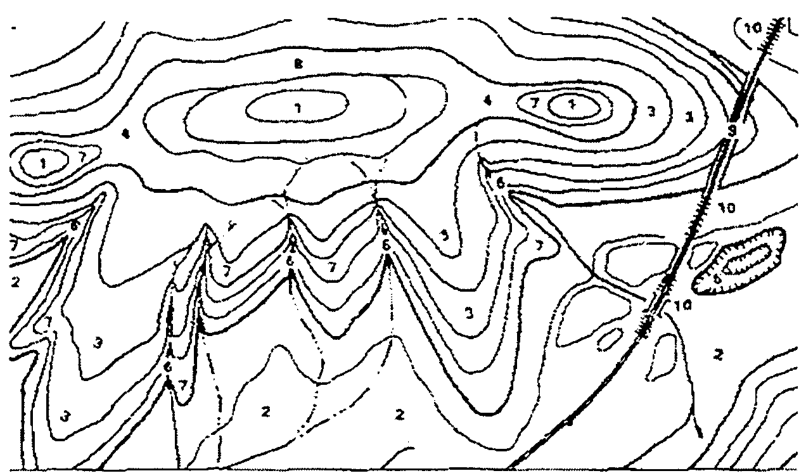


Figure 4. Terrain Feature Description Using Contour Lines (FM 21-26, 1993)

DTED Level	Post Spacing
0	100 m
1	100 m
2	30 m
3	10 m
4	3 m
5	1 m

Table 2. DTED Level Post Spacings (FAS, 1997)

All forces are interested in the enemy's geographic location relative to surrounding terrain because it is an indication of what the enemy is prepared to do, but air and land forces view the terrain map differently when considering their own maneuver. Mechanized ground forces prefer wide-open terrain because it gives them the ability to maneuver. Terrain with prominent elevation features provides mobile forces such as aircraft or small infantry units with landmarks to navigate by and can offer cover, concealment, and observation areas.

2. Color

Standardized coloring schemes are often used to encode background information. Table 1 provides a list of colors and their corresponding encoded features on military charts (FM 21-26, 1993). Differences in color are adequate to identify major differences between areas such as the difference between land and water or between desert and forest. A problem with the coloring scheme is that it does not identify subclasses that comprise a color's usage. For example, areas shaded green depict vegetation of military

significance, but the chart may not describe or differentiate between kinds of vegetation, such as triple canopy jungle or mangrove swamp (Gorski, 1999). Therefore, the inadequate terrain description contained in the map could lead to poor choices in the planning process.

3. Strengths/Weaknesses

Military maps are excellent planning tools because they offer a common medium for forces executing widely disparate functions. They provide a baseline for information in a standardized format regarding an area of interest. All combat forces receive map reading and navigation training as part of their initial military education, such as boot camp or officer candidate school.

The weaknesses associated with this format include accuracy, information latency, and coverage. As a scaled approximation of the Earth's surface, it cannot account for every possible feature or it would become too cluttered to be of any utility. Therefore, the planner must also ask the question, "What information has been left off the map?" In addition, inaccuracies associated with scaling and data extrapolation make the topographical map too imprecise for planning precision-guided munitions employment (Tenet, 1999; Pickering, 1999). Information latency occurs when differences between the maps representation and reality are caused by changes over time. Typically, the information contained in a map that has not been regularly updated with pen and ink changes is at least three to five years old (Gervais, 1999). When US forces commenced Operation Desert Storm, the most current maps in stock were produced during World

War II. Consequently, one of the first support actions that occurs during any crisis is updating the maps (Bernard and Trainor, 1995). Commercial development and natural weather phenomena also change the terrain, making the data displayed on the map inaccurate. Littoral areas that amphibious forces might operate in are especially prone these effects. This information difference between the maps and the actual environment may lead to a poorer mission plan. Finally, worldwide map coverage does not exist at all scales (FM 21-26, 1993). As resources to update maps are limited, emphasis is placed on updating and creating maps where US forces currently deploy or will execute most operations.

Imagery formats become an important source in regions where inaccurate, incomplete map coverage exists. However, before discussing any individual imagery format, some of the issues common to all formats are reviewed.

B. IMAGE FORMAT COMMONALTIES

All of the images that the analyst interprets are captured by remote sensing systems, which record the intensity of electromagnetic radiation that objects reflect, emit, or scatter in a particular wavelength band (Sabins, 1997). As the sensor records data, it captures spatial characteristics about the Earth's surface (Aerospace Corp., 1998). Figure 5 displays the portion of the electromagnetic spectrum exploited by remote sensing. The multicolored section of the figure is a graph of atmospheric transmittance as a function of wavelength. The dark shaded areas are absorption bands where the various elements and compounds found in the Earth's atmosphere reduce the amount of available energy for

the sensor to collect. The light areas are places where electromagnetic radiation passes through the atmosphere with little or no absorption. (Short, 1999). The upper portion of the figure characterizes the portions of the spectrum.

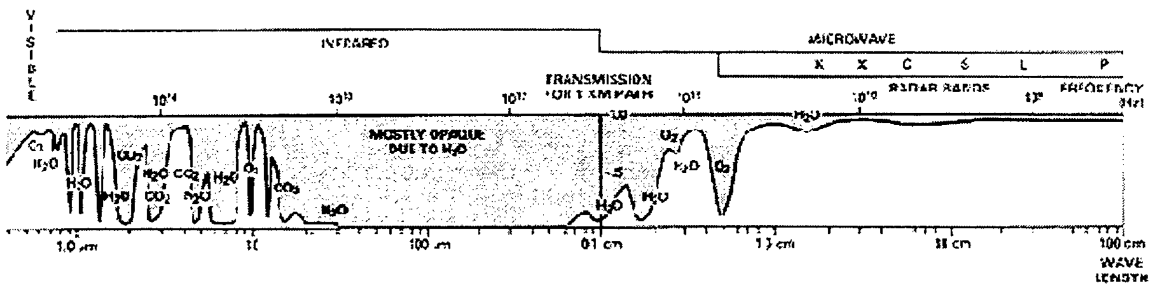


Figure 5. Electromagnetic Spectrum Utilized in Remote Sensing (From Short, 1999)

In each spectral range, the reflectance, or albedo, helps distinguish various objects from each other. The relative reflectance of two objects may vary with wavelength. Sample signatures for natural and man made materials are provided in Figure 6. For any given sensor, the object's spectral signature partially determines its appearance relative to other objects in the scene. The analyst's ability to distinguish and measure objects in an image is also dependent on the object's size, sensor quality, and contrast level between the object and the background (MUG, 1995).

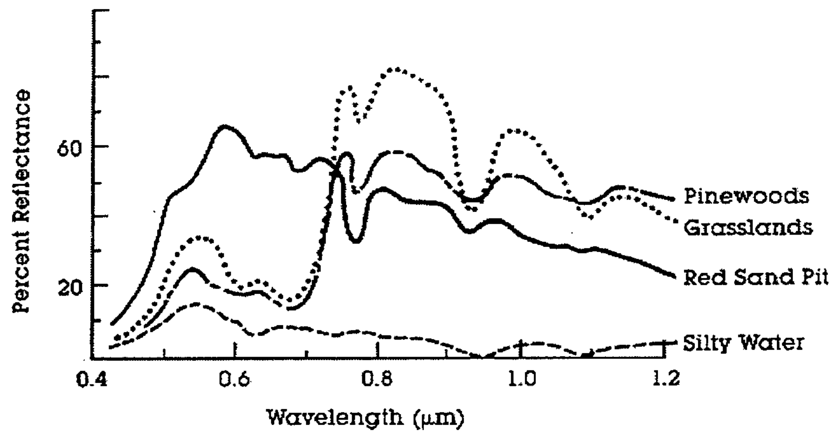


Figure 6. Sample Spectral Signatures (Short, 1999)

1. Image Properties

The primary properties that all image formats possess are scale, brightness, tone, contrast, and resolution (Sabins, 1997). Scale and contrast are ratios. Scale is the ratio of image distances to their physical counterparts, and contrast is the ratio between the highest and lowest brightness values in an image. Brightness and tone describe characteristics of the returned electromagnetic energy. Brightness is a measure of the reflected energy intensity at a particular wavelength. Tone quantifies distinguishable variations in electromagnetic energy (Sabins, 1997). Resolution is a metric for sensor data quality with respect to a given dimension (MUG, 1995).

Each of the properties described above has a different meaning depending on sensor type, and analyst's expert knowledge of these information assists in interpreting the scene. For example, the analyst will interpret brightness differences three different ways depending on whether a panchromatic, thermal IR, or radar sensor produced the source image. In a panchromatic image, brightness captures the ability of different objects to reflect solar energy; in general, better energy reflectors are poorer energy

absorbers. As a result, brighter objects in panchromatic images are cooler than darker ones. However, in the thermal IR warmer objects provide a stronger return and therefore appear brighter in a scene. Brightness in a radar image is a function of the object's geometric shape with relation to the sensor (Sabins, 1997). Personnel with little or no interpretation experience might assume that any image they receive is a photograph. This mistake could lead to confusion in interpretation of the image and subsequently result in a flawed mission plan.

2. Metrics of Quality

Resolution is a measure of the quality of the information extracted from a sensor with respect to either the spatial, radiometric, or spectral dimensions (MUG, 1995).

a. GSD

Spatial resolution or Ground Separation Distance (GSD) is the minimum required distance between two objects for those objects to appear distinct and separate. GSD is expressed in units of distance and can be approximated by Formula [1] (Sabins, 1997). Therefore, an image with better GSD allows the analyst to see objects that are closer together.

$$GSD \approx (\lambda/D)\,H, \text{ where:} \qquad [1]$$

λ = electromagnetic energy wavelength captured

D = optic diameter

H = slant distance from the object to the sensor

b. Radiometric

Radiometric resolution is a measure of sensors' sensitivity to differences in radiance and is expressed as a number of bits (MUG, 1995). For n bits, 2^n independent states can represent the energy at a point. Using more bits to represent a single pixel increases the number of states, increasing accuracy of the display and lowering the quantization error associated with digitally encoding data (Tomasi, 1998). It also increases the transmission requirements for the data, because all the bits are required to display that pixel. Therefore, better radiometric resolution provides the analyst a more accurate image to interpret.

c. Spectral

Spectral resolution is a description of what energies are being collected along the electromagnetic spectrum and how precisely they are measured. Figure 7 displays spectral resolution for multispectral and hyperspectral imagery. More wavelength bands allow the analyst to process via non-literal means.

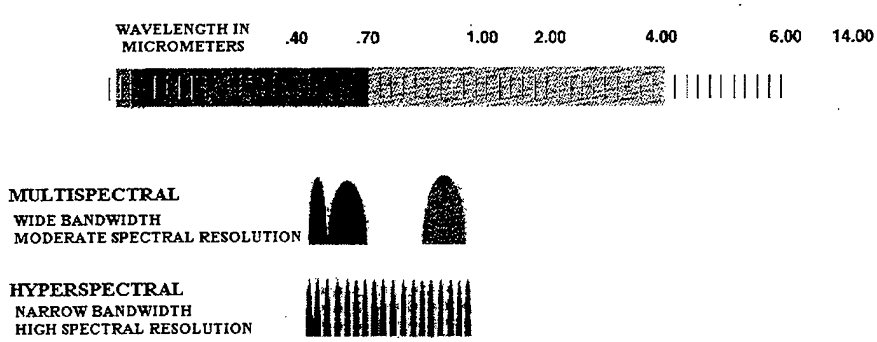


Figure 7. Spectral Resolution Comparison for Spectral Imaging Sensors (From MUG, 1995)

d. Interpretability

In the past, spatial resolution was the most often quoted metric for information quality, but it has been replaced by interpretability for determining the analyst's ability to correctly answer questions regarding a scene (Aerospace Corp, 1998). Figure 8 displays four images in two different formats that have the same GSD. A panchromatic imager produced the images in the upper row; a multispectral imager produced the images in the lower row. Images from systems in the left column exhibit good contrast and low noise, while images from the systems in the right column exhibit high noise and low contrast. NIIRS and MSIIRS were developed to give analysts a method to convey the interpretability of an image to others (IRARS, 1995).

(1) NIIRS. The National Imagery Interpretability Rating Scale (NIIRS) is a standard adopted by multiple communities including, remote sensing and intelligence. Initially developed in the 1970s, NIIRS is a numerical scale for rating image quality based on independent textual criteria. The scale initially focused on military-related criteria and was later expanded to include civil applications. The basis for the rating criteria is image interpretation tasks that the analyst performs routinely. NIIRS scale values range from 0 to 9. The higher the numerical value assigned to an image, the more information contained in the image. The top left image in Figure 8 would be between a NIIRS 5 and 6. The image is closer to NIIRS 6 because the aircraft on the tarmac are easily identifiable (NIIRS 5) but car types such as sedans or station wagons (NIIRS 6) cannot be determined. The top right image would be rated as NIIRS level 4

because the wing type differences between the small fighter aircraft on the tarmac are identifiable and less information can be extracted from the rest of the image (IRARS, 1996).

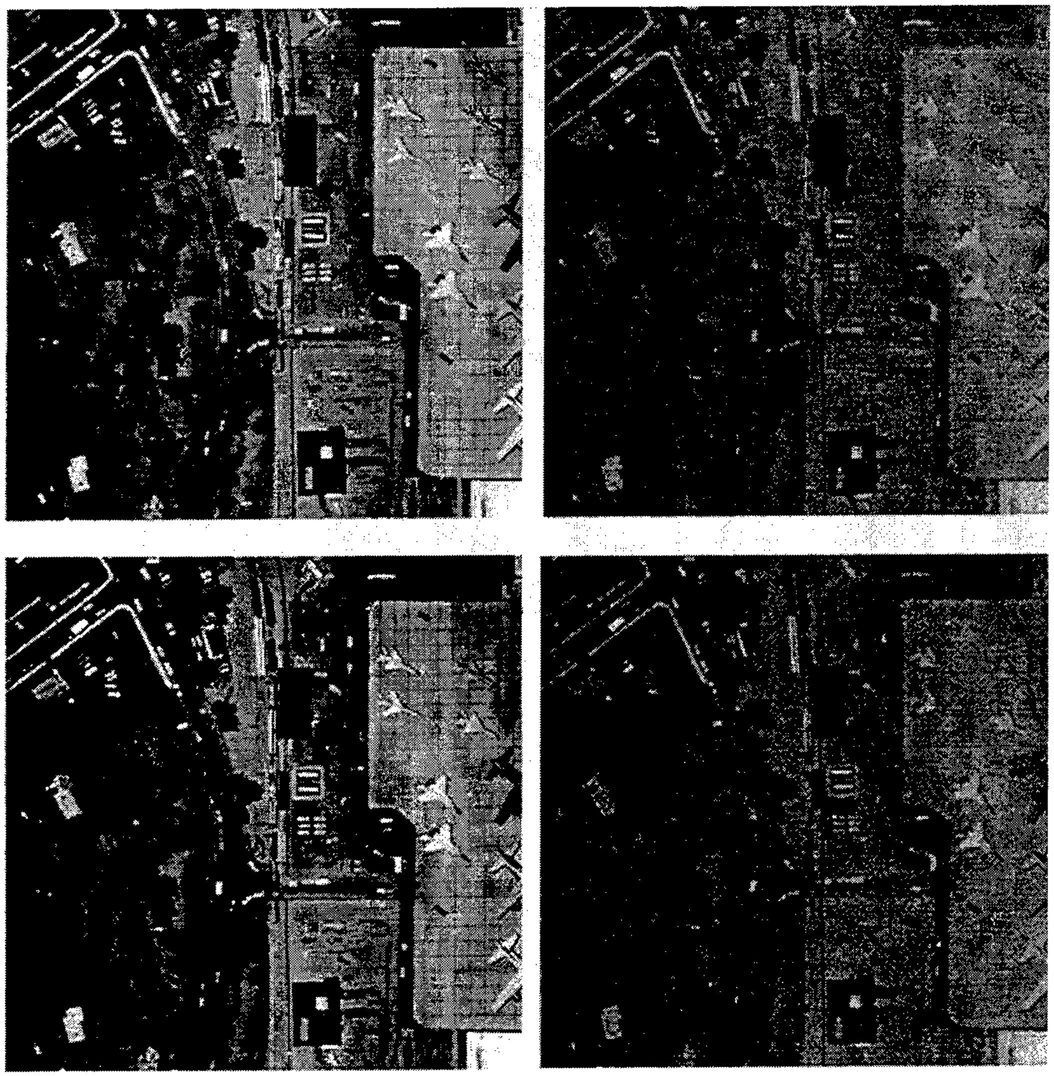


Figure 8. Images with Identical GSD and Varying Image Quality (IRARS, 1995)

(2) MSIIRS. The Multispectral Imagery Interpretability Rating Scale (MSIIRS) was modeled after NIIRS in 1993 to provide a common metric

system for manual exploitation of multispectral imagery in the wavelength range of 0.4 to 2.5 μm. Unlike NIIRS, MSIIRS is not a community-sanctioned standard. MSIIRS values have a range of 0 to 7, based on a generic scale with additional criteria for a wide variety of specialized interpretation tasks such as urban, military, or natural. The scale is less concrete than NIIRS because the image analysts are free to exploit the image using any band combination they choose. The lower left image in Figure 8 could be assigned a MSIIRS level 5 because individual cars are identifiable in the parking lot located just above the slightly wooded area (IRARS, 1995). While NIIRS and MSIIRS are similar concepts, they have completely separate criteria that are not meant as a cross-reference between images of different formats (IRARS, 1995; IRARS, 1996).

C. TRADITIONAL IMAGERY

The traditional imagery available to the imagery analyst and mission planner comes from airborne and space platforms, in either soft or hard copy. If in hard copy, the material may be a paper product, or a transparency that can be viewed on a light table. The trend today is towards soft-copy, which can be exploited on a computer, and manipulated using a variety of image processing tools. Traditional imagery formats are panchromatic, infrared, radar and single band MSI.

1. Panchromatic Imagery

Panchromatic sensors record reflected solar energy as a single spectral band in the visible region, approximately 0.4 to 0.7 μm, of the electromagnetic spectrum (Sabins,

1997). While understanding how objects reflect or absorb solar energy in this region is important, the importance is reduced for interpreting panchromatic imagery because much of the general knowledge the interpreter uses in this format is based on human experience. The brightest areas in an image represent objects that reflect or scatter incident energy best within a scene. Conversely, objects that absorb energy best within a scene are the darkest areas of a picture. If a panchromatic scene contained the objects whose spectra are described in Figure 6, the red sandpit would be the brightest object in the gray scale display, followed by pinewoods and grasslands. The darkest object in the scene would be the silty water (Short, 1999). The gray scale differences can then be grouped together into different ways that allow the analyst to use other elements of recognition to interpret the scene.

If the analyst has two images of the same area that differ only in perspective, he may choose to interpret the image using stereoscopy. The technique takes advantage of the human visual system to produce a three-dimensional image in the analyst's brain by using two two-dimensional images and a stereoscope (Sabins, 1997). Without stereoscopy, the analyst can obtain only limited information about terrain relief. In this case, marginal terrain relief can be obtained by analyzing how the sun strikes the earth in the image or from object layover.

Object layover make the tops of taller objects within a scene appear to lean away from the optical center of the image. The effect is created because the photons carrying information about the top of an object arrive at the sensor from a different angle than the photons carrying information about the bottom of the structure. Since the sensor can only

generate a two-dimensional image, the photons from the object are transposed onto the image plane away from the optical center of the image. Figure 9 displays an aerial photograph with layover and a pictorial description of the effect. Look angle, object height, and relative displacement from the optical center of the image will all affect the level of distortion created. A trained analyst uses layover as a tool to obtain relief data using simple geometry (Sabins, 1997).

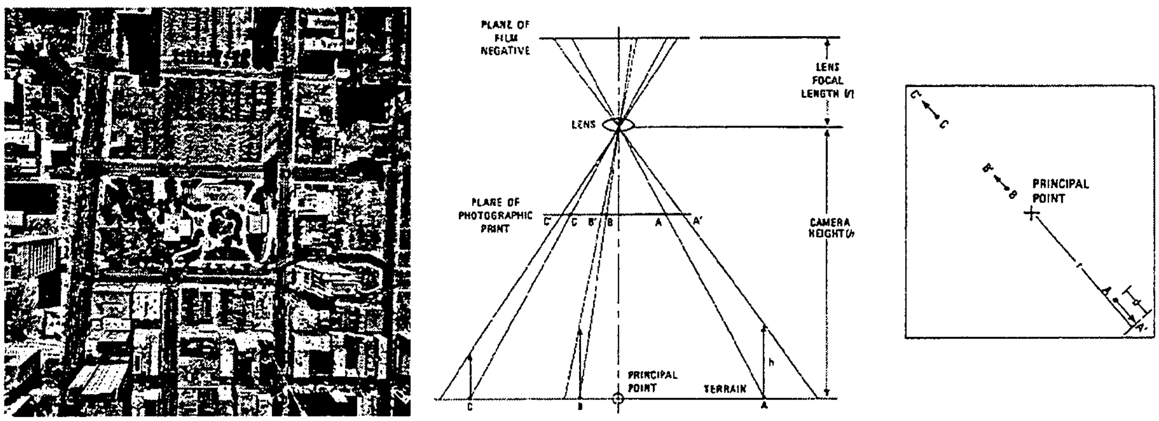


Figure 9. Example of Layover in Aerial Photography and Explanation (Sabins, 1997)

The strongest advantage of the panchromatic format is that the analyst can easily describe the final assessment in terms the mission planner understands and trusts. Panchromatic images also provide more quantitative and qualitative intelligence about an area than a map does (FM 21-26, 1993). However, daylight and fair weather are essential for successful imaging (Sabins, 1997). Obscurants such as water vapor or smoke render panchromatic sensors useless because the sensor captures the reflected solar energy of the

obscurant, not the target of interest. In addition, raw images will not contain precise location data when compared to a map (FM 21-26, 1993).

2. Infrared Imagery

The infrared portion of the electromagnetic spectrum can be divided into two major sections. Reflected infrared includes the near infrared (0.7 to 1.2 μm) and short wave infrared (1.2 to 3.0 μm) regions of the electromagnetic spectrum. Thermal or Long Wave Infrared is located from 3 to 15 μm the electromagnetic spectrum. The wavelength band from 5-8 μm is an atmospheric absorption band of electromagnetic energy (Sabins, 1997).

a. Reflected IR

Solar energy dominates the reflected IR region. An object's appearance in gray scale is based on its reflectance values in this region, which is the same phenomenon as panchromatic. However, the amount of spectral reflectance for different objects can vary from the visible region. One such example is vegetation. The solar reflectance for certain vegetation types dramatically increases at approximately 0.8 μm. Using this "IR ledge" is one method of finding camouflaged objects. True vegetation in this region is very bright, while cut vegetation and camouflage material appear dark (MUG, 1995). If a scene containing the objects of Figure 6 were imaged in the reflected IR, grasslands would be the brightest objects in the scene, followed by pinewoods and the red sandpit, with silty water still being the darkest object (Short, 1999). The scene will not appear the

same as a similar image in the visible region. This effect can be confusing to untrained personnel and may lead to a poorer mission plan.

b. Thermal IR

Observations at longer wavelengths are controlled by the thermal emission from the targets, and the scene dynamics differ from those described above for the reflective IR domain. Figure 10 is a graph of Plank black body radiation formula for two objects (Gettys, 1989). The dashed line depicts ideal blackbody solar energy at the Earth's surface. The solid line depicts an object with an approximate temperature of 300°K. Energy from solar emissions dominates the graph up to approximately 3-5 μm, after which object emission dominates. Hence, FLIR and other observations in the MWIR and LWIR are largely independent of solar illumination. Another advantage thermal IR sensors provide over panchromatic is that airborne particles such as smoke and dust have a reduced effect as an obscurant because the particles themselves are smaller than the energy wavelengths of interest (Sabins, 1997; Aerospace Corp., 1998).

Image characteristics will often appear similar to panchromatic imagery because both formats record information as gray-scale variations. The brightest tones on thermal IR images represent the objects with the most radiant energy, while darker tones correspond to objects with the least radiant energy. This explanation is still incomplete, because two objects such as wood and metal that have the same absolute temperature would nominally radiate the same amount of energy, and therefore they would be indistinguishable to the analyst. Fortunately, just as the reflective character of targets

varies from material to material, so does the "emissivity," or the relative ability of an object to emit radiation, in comparison to an ideal "black body." These variations are relatively subtle (a few percent, typically) but sufficient to enhance the utility of IR sensors in distinguishing targets that are otherwise not distinguishable. The object's other thermal characteristics such as inertia, conductivity, and capacity determines an object's ability to absorb and retain heat. In turn, these attributes as well as atmospheric effects impact how an object appears relative to its environment in a given image (Short, 1999).

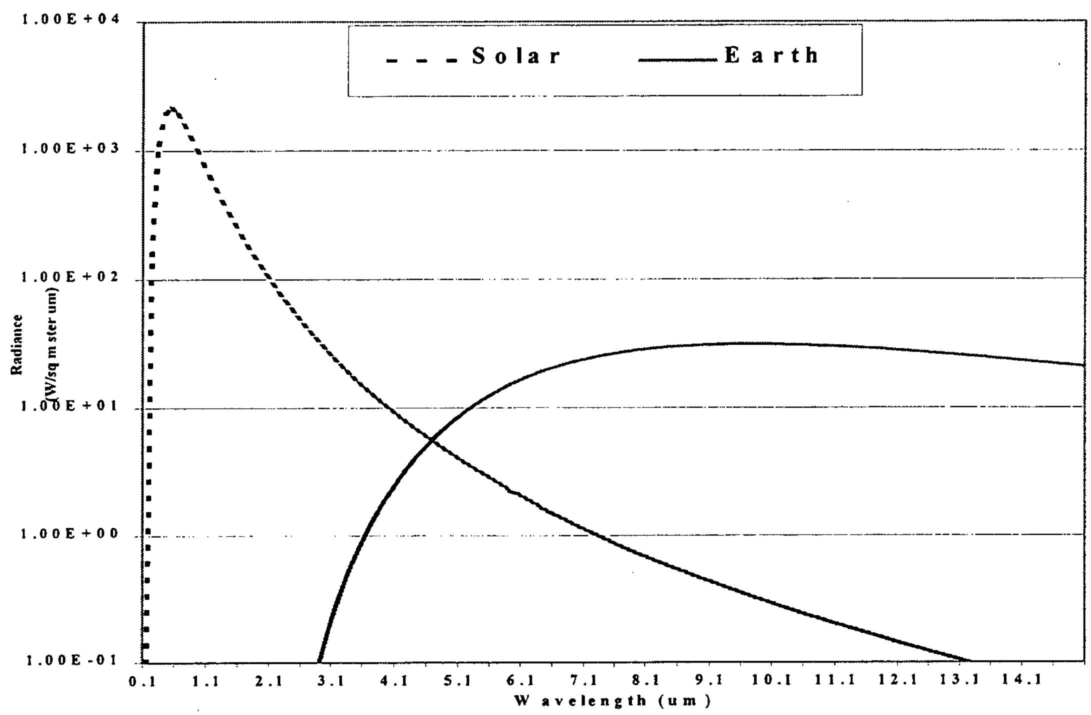


Figure 10. Planck's Blackbody Radiation Curves for the Sun and the Earth Measured at the Earth's Surface (After Gettys, 1989)

Several phenomena on thermal IR images can be confusing to the untrained user. Figure 11 displays diurnal temperature variations for various objects that could comprise a scene. In the early morning hours and in late evening, the brightest objects in the scene are vegetation, followed by standing water, rocks/soil, damp terrain, and metallic materials. However, between local sunrise and local sunset rocks and soil become the most radiant objects in the scene so they would appear the brightest (Sabins, 1997). In addition, wind patterns that cool selected objects can produce streaks on the image that could be interpreted as significant tonal variations. Therefore, without a basic understanding of these effects, image misinterpretation is possible.

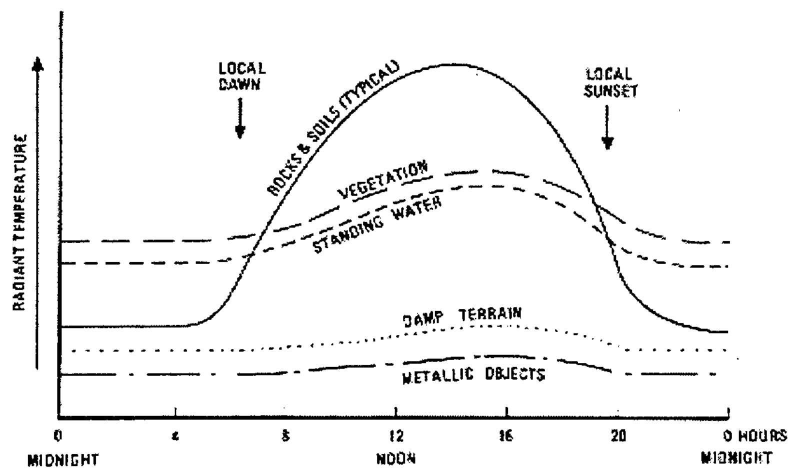


Figure 11. Diurnal Temperature Variations for Selected Objects (Sabins, 1997)

System resolution is another challenge the analyst faces when interpreting thermal IR images. Formula [1] shows that the GSD is proportional to the collected wavelength λ. Since thermal IR wavelengths are an order of magnitude longer than visible wavelengths, the GSD between comparably sized objects must increase by the same amount in order for those objects to appear distinct, for a given optical system.

Therefore, an analyst who relies heavily on GSD can be hampered in his or her efforts to interpret thermal IR imagery. This effect is illustrated using LANDSAT TM imagery in Figure 13. Bands 1 and 2 are both images in the visible portion of the spectrum while Band 6 images the thermal IR. The band 6 image is clearly less sharp than Bands 1 and 2 (Short, 1999).

The strengths of using thermal infrared images include the fact that the medium captures information outside the range of the human eye. Sensors do not require solar illumination for imaging and weather has a reduced impact on this format when compared to panchromatic. The major disadvantage associated with this format is the confusion an untrained user might encounter.

3. Radar Imagery

Radar imaging systems create an image by transmitting electromagnetic energy from selected wavelengths from 0.1 to 100 cm, then capturing the reflected electromagnetic energy. The long wavelengths would nominally lead to very poor resolution given the applicability of equation [1]. Increased spatial resolution is attained by using a very large antenna, which can be produced a virtual method such as synthetic aperture radar (Sabins, 1997).

Radar sensors provide their own illumination. Therefore, they are not dependent on solar reflection or thermal emission for successful imaging. In addition, atmospheric effects such as absorption in this portion of the electromagnetic spectrum are substantially reduced.

Pixel brightness in a radar image indicates spots where the transmitted energy was returned to the sensor. Objects with steep slopes towards the antenna produce strong returns, thus bright pixels. Corner reflectors such as buildings produce the strongest returns. Objects with steep slopes facing away from the antenna produce very low returns or dark pixels, because no energy reaches the area. Objects that scatter energy in all directions such as vegetation produce intermediate returns. Smooth surfaces such as pavement or water reflect energy away from the antenna thus producing very small returns (Sabins, 1997). Figure 12 is a radar image of the Pentagon that shows these effects. The exterior shape of the Pentagon is very strong, while the roads at the bottom of the image are very dark. The vegetation in the courtyard at the center of the Pentagon produces the intermediate tones described.

Smoothness is relative to the imaging system wavelength. An object such as pavement appears rough in the visible region because the pavement scatters, rather than reflects, most of the incident energy. However, the radar's wavelengths are thousands of times greater than those in the visible region, so the pavement reflects most of the energy away. A surface is considered smooth if it meets the criterion shown in Formula [2] (Sabins, 1997).

$h < \lambda \, (8 \sin \gamma)^{-1}$, where: [2]

h = vertical relief

λ = wavelength

γ = depression angle (angular measure of how far down the sensor is pointed from the horizontal)

Phenomena such as object layover, relative motion, and topographic inversion also present challenges to interpreting radar images. Radar images also experience object layover, but it is reversed from the perspective found in panchromatic. When an object with large vertical relief is imaged, the reflected energy from the top of the object arrives at the sensor earlier than energy from the bottom of the object; therefore, the object appears to lean toward the sensor. When the object sensed is in motion, distortion or smearing can be produced because there are multiple returns in different places for the same object (Sabins, 1997). Topographic inversion is produced when the brain unsuccessfully guesses the relative location of an illumination source when attempting to determine terrain relief. An unsuccessful guess causes ridges to look like valleys and vice versa (Sabins, 1997).

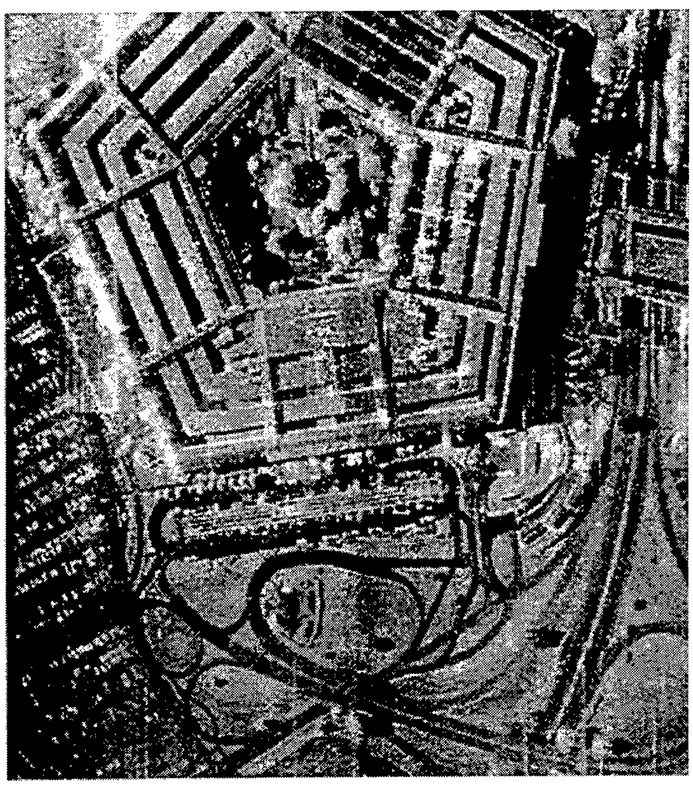


Figure 12. Radar Image of the Pentagon (FAS, 1997)

The major advantage of radar images is that they are completely independent of both lighting conditions and weather. The major disadvantage associated with radar is the same as Thermal IR; the image format requires increased training to properly interpret.

4. Single Band Multispectral Imagery (MSI)

Multispectral imagery is on the boundary of current operational tools and the specialized analysis domain of the expert, such as the mapmakers at NIMA. Still, imagery analysts can utilize multi-spectral imagery, such as that obtained from the LANDSAT satellites. Its distinction from traditional military systems is that multispectral sensors collect the energy intensity simultaneously from two or more contiguous regions of the electromagnetic spectrum, recording the intensity values separately (MUG, 1995). MSI sensors probe several transmission windows in the .4 to 13 μm region of the electromagnetic spectrum. The collected energy is some combination of solar energy and thermal radiation that varies as a function of wavelength (Aerospace Corporation, 1998). For example, the LANDSAT Thematic Mapping (TM) Satellite has seven spectral bands (values in μm): 1(0.45-0.52), 2(0.52-0.6), 3(0.63-0.69), 4(0.76-0.9), 5(1.55-1.75), 6(10.4-12.5), and 7(2.08-2.35) (Sabins, 1997). Interpreting one band of LANSAT imagery independently of the other bands allows the image to be displayed as a gray scale image.

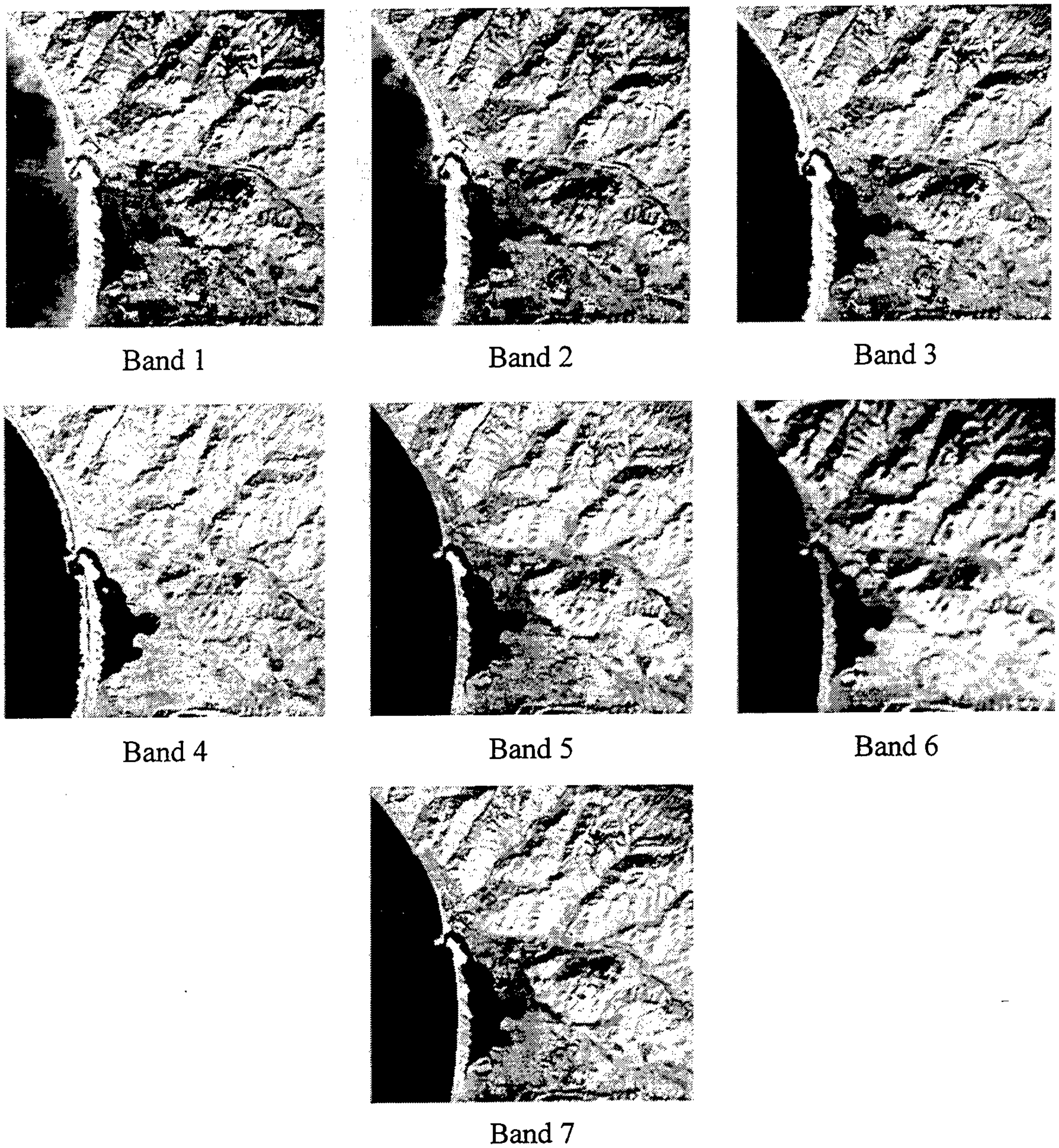


Figure 13. LANDSAT TM Imagery of Morro Bay, CA (Short, 1999)

The environmental characteristics the sensor responds to are a function of the band interpreted, which means the same scene will appear slightly different in each band. Figure 13 displays this effect for Morro Bay, California. For example, LANDSAT TM

bands 1 and 2 are both in the visible region, but band 1 is more sensitive to natural blue light, while band 2 is more sensitive to natural green light. Neither band is sensitive to red or infrared light. Since the analyst understands this, he or she might use this technique to locate or describe objects that have high contrast in one of these bands. LANDSAT bands 4, 5, and 7 responds to the reflected IR energy and band 6 respond to thermal IR differences in a scene.

5. Summary

To summarize, when an image that represents a portion of the Earth surface contains information that comes from a single spectral region, it may be interpreted literally in gray scale. Each sensor encodes the information into gray scale differently. Therefore, the analyst must understand the method the sensor uses to capture and record the energy as well as certain physical effects to prevent misinterpretation.

D. SPECTRAL IMAGERY

In certain cases, a single gray scale image does not give the analyst enough information about the area of interest to meet all the planner's requirements. While a multispectral sensor may physically capture the photons only once, it creates as many images as there are bands. By performing additional processing on the scene, it is possible to combine the effects of multiple bands into a single image that generate additional visual cues for the analyst to interpret. If the additional processing is not performed, it is likely that the resulting scene will provide no additional information

about the scene than any other original images independently. Each of these formats (MSI, HSI, and sensor fusion) gives the interpreter the ability to analyze the image using literal and non-literal means.

1. Multispectral Images (MSI)

Multispectral image interpretation allows the user to combine the several spectral bands to create image products that differ significantly from the single band gray scale images described previously. Coupling the information in the bands with object spectral reflectance characteristics can result in higher information extraction when compared to a panchromatic image (Sabins, 1997). The methods for interpreting MSI include true and false color composites, classification, and principal components analysis.

a. True Color Composites

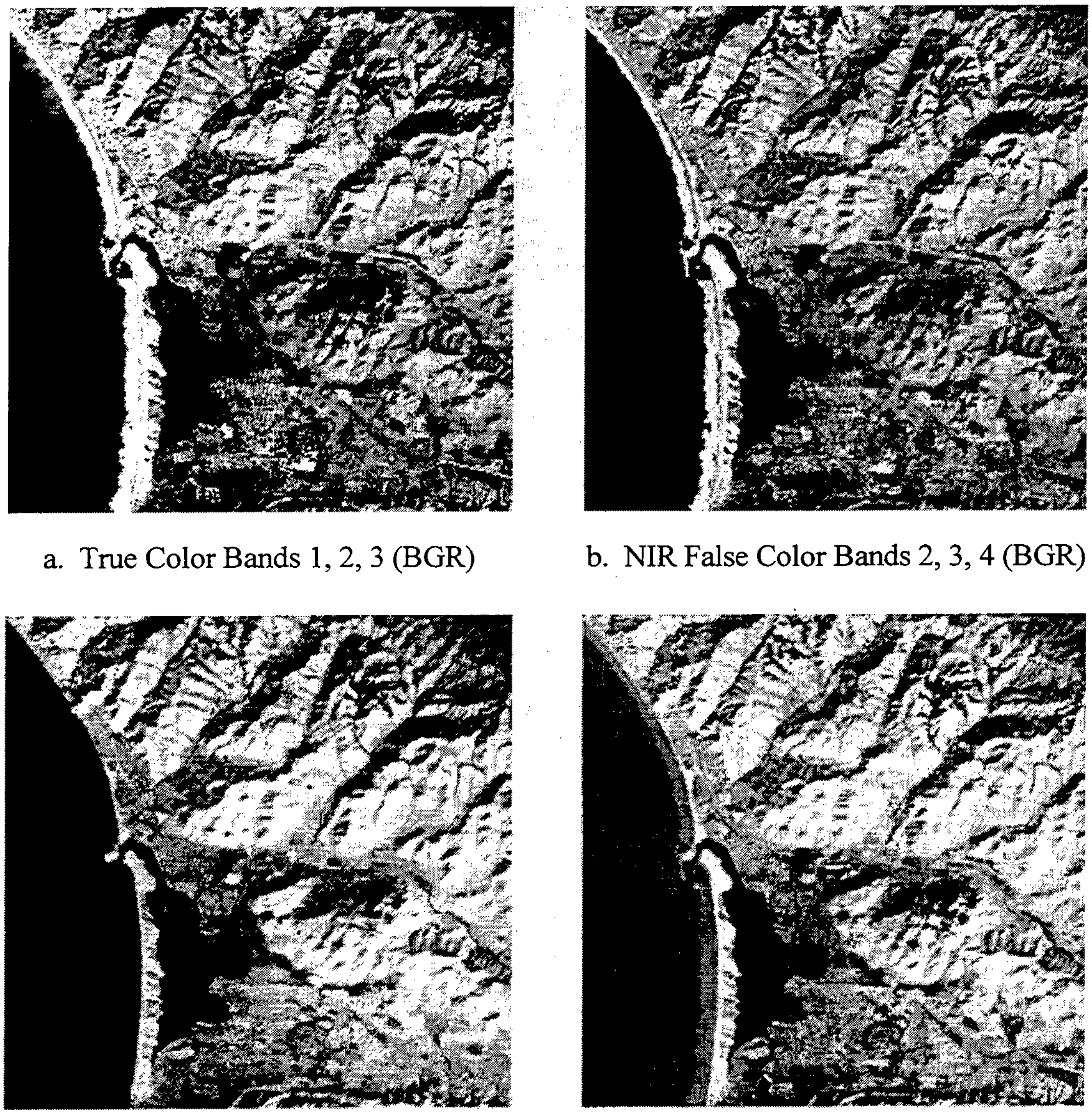
Joint Intelligence Centers have the capability to produce products such as true color composites. While the production method falls into the realm of spectral analysis because the analyst combines information from several spectral bands to produce the image, the end product is an image that can be interpreted literally without additional training. Color, shape, and size constancies are easy to establish, because the objects in the scene appear as they do in human experience. This sort of product can be an excellent planning tool for the military if the season in which the sensor captures the data coincides with the season the operation in which occurs.

A natural extension of the single band multispectral image interpretation described earlier is to integrate color as a method of conveying information. The most common images produced using MSI data are three-band color composites, which assign each a band different color gun (MUG, 1995). Each pixel usually has three digital numbers assigned: red, green, and blue. After each color gun is fired, the colors mix in an additive manner for each pixel on the analyst's computer monitor.

A true color image matches the spectral data for red, green, and blue information to the red, green, and blue color guns. Figure 14.a displays a LANDSAT TM true color image of Morro Bay, CA (Short, 1999). Most objects in the image appear as they would by direct human observation, such as from an airplane window. The water around the coast is blue, the golf course on the east coast of the bay just south of the inlet is green, and the urban area is characterized by the light gray grid of streets, as are the two highways coming and out of the town (Short, 1999).

However, certain objects in Figure 14.a still do not appear the way they would through direct observation. For example, the Pacific Ocean to the west of Morro Bay is still too dark because water vapor in the atmosphere absorbs energy from this area before it reaches the sensor (Short, 1999). The most unrealistic color in the scene is the hill slope. It should be a golden brown, but is displayed with a purple tone. The reason for this color distortion is grounded in physics. Each band of energy in the image reacts differently to refraction, reflection, and absorption in the Earth's atmosphere. Subsequently, greater or lesser amounts of that energy arrive at the sensor than the value required to "mix" the proper color. In Figure 14.a, more red light arrives at the sensor

than blue and even less green, which creates the color mixture displayed (Short, 1999). Table 3 provides a textual listing of how other features are displayed in true color images.



a. True Color Bands 1, 2, 3 (BGR)

b. NIR False Color Bands 2, 3, 4 (BGR)

c. False Color TM Bands 5, 7, 6 (BGR)

d. False Color TM Bands 4, 7, 1 (BGR)

Figure 14. True and False Color Composite Images of Morro Bay, CA (Short, 1999)

b. False Color Composites

Whenever the analyst selects a color scheme that does not equate the red, green, and blue (RGB) color guns to RGB information in the image, a false color image is generated. Any color image that displays spectral information that the human eye cannot perceive as a color is false color. Near IR (NIR) and SWIR are the most common formats for MSI pictures. Table 3 describes the color gun assignments for NIR and SWIR false color composites as well as a textual description of how objects are colored in these images (MUG, 1995).

	True Color	Near IR	Short Wave IR
Blue Gun displays	visible blue	visible green	visible red
Green Gun Displays	visible green	visible red	near IR
Red Gun displays	visible red	near IR	short wave IR
Trees and Bushes	olive green	red	shades of green depending on band color gun combinations
Crops	medium to light green	pink to red	shades of green depending on band color gun combinations
Wetland Vegetation	dark green to black	dark red	shades of green depending on band color gun combinations
Water	shades of blue and green	shades of blue	black
Urban Areas	white to light blue	blue to gray	lavender
Bare Soil	white to light gray	blue to gray	magenta, lavender or pale pink

Table 3. General Appearance of Features in Various Composite Images (MUG, 1995)

Figure 14.b displays a false color composite of Morro Bay, CA. LANDSAT TM Band 2, which is natural green light, was assigned to the blue color gun. Band 3, which is natural red light, was assigned to the green color gun. Finally Band 4, which is reflected IR, was assigned to the red color gun. This corresponds to what one would see with traditional "IR" film. The previous discussion of reflected IR described how healthy vegetation appears very bright in the reflected IR. This correlates to the bright red colored areas in the image. Based on the level of red tint in different sections of the scene, the analyst can coarsely classify vegetation types (Short, 1999).

In addition, the nearshore areas of the Pacific Ocean in the scene are lighter because the sediment in the water adds reflectance to the scene. In planning an amphibious mission, the planner would want to avoid areas where he or she could see blue very far away from shore because it could be an indication of shallow slope which traditional displacement landing craft may run aground on. This shallow slope problem was one of the concerns that planners during Operation Desert Storm faced in preparing the amphibious assault of Kuwait (Gordon and Trainor, 1995).

Figures 14.c and 14.d are two other examples of false color images. Figure 14.c is used to convey information about thermal differences based on band selection. Just as in other relative temperature plots, shades of blue represent the coolest areas of the image, while the red shades represent the warmest colors in the image (Short, 1999). Specific temperatures are not assigned to the color hues, so this information could be misleading to a planner if the temperature difference were only 10°C. Figure 14.d shows each of the major features of the image in a primary color. Vegetated areas are

displayed in bright blue; bright reds classify the surf, towns, and other hydrographic characteristics; greens are uncultivated areas (Short, 1999).

Figures 14.c and 14.d illustrate a major drawback in false color image use for military planning; they are disturbing to the untrained user because they violate the concepts of color constancy. People expect water to be blue and grass to be green regardless of illumination conditions. When objects such as these appear in a different color without explanation, the viewer can become confused. If the image analyst cannot explain what the color scheme means in a concise fashion that the planner can understand and apply, then the planner will probably be thrown off by the fact that the colors are wrong and be less likely to use that information in the planning process. The US Department of Defense (DOD) appears to have minimized this problem in MSI by using only certain false color composite image types. With the number of types minimized, the analyst and the planner can use keys similar to Table 3 to interpret how different features appear in different color groupings (MUG, 1995).

c. *Digital Image Processing*

There are several digital processing techniques available for the analyst's use in order to extract information from a scene. Principle Components Analysis and Classification are just two of the digital image processing techniques that take advantage of the fact that there are several DNs for each pixel, each representing different spectral information.

If the individual images in Figure 13 are quickly reviewed, they all appear very similar except band 6. Principal Component Analysis (PCA) is one processing technique that uses all available spectral bands to create the same number of new images. However, the first few principal component (PC) images contain most of the variability between bands and most of the remaining images are noise. If materials within a scene have significantly different spectra, this may aid in target discrimination. This effect can be seen in the seven PC images of Morro Bay in Figure 15. PC 1 is generally a weighted average of all the spectral bands that looks like a black and white photograph. PC 7 and possibly PC 6 can be considered noisy. Additional PC images highlight different features in the scene that the analyst can literally interpret, provided the analyst has the associated knowledge to accompany the image (Richards, 1999).

The PC images may also be combined into a color composite. PC color composites utilize more of the available color because each PC image highlights uncorrelated differences, while the standard color composite does not (Richards, 1999). Figure 15 displays a PC color composite by assigning the information from PC images 1, 2, and 3 to the blue, green, and red color guns, respectively.

An advantage of PCA is that only the first few images require interpretation. Another advantage is that sensor noise that is inherent in all bands is reduced. Therefore, the multi-band data set is effectively reduced to a single, lower-noise, gray-scale image that is suitable for transport over low bandwidth communications circuits (Short, 1999; Sabins, 1999). A disadvantage is that if the analyst or planner does

not understand how this processed image differs from the original, then the advantage of PCA is lost.

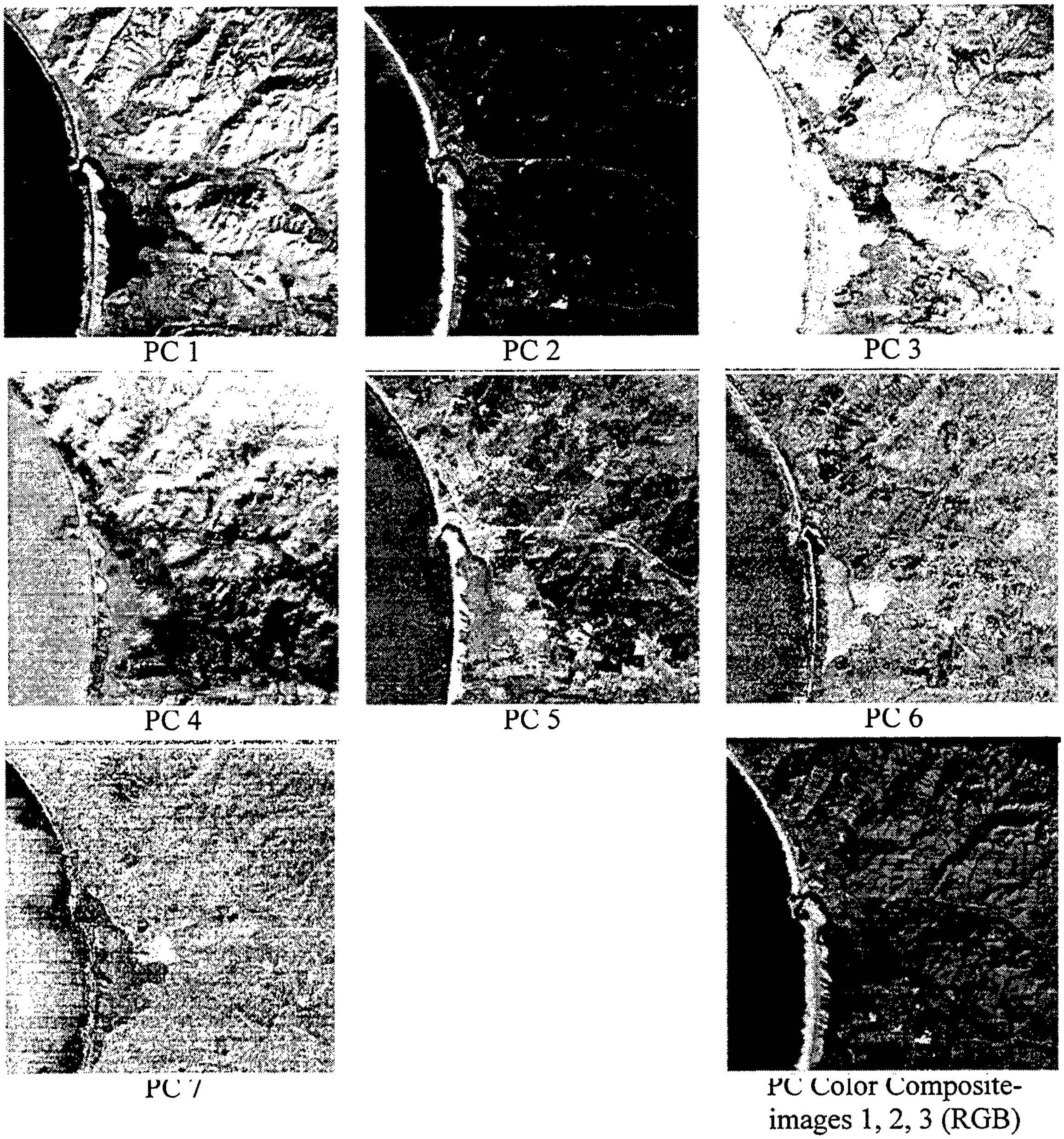


Figure 15. PC Component Images of Morro Bay, CA (Short, 1999)

Classification groups pixels in a scene based on known spectral class criteria. Selecting n bands from the available data sets creates an n-dimensional

classification space. Each band becomes an orthogonal axis to the others. The pixels in the scene are mapped into the space based on their DNs for each band and can then be grouped by comparing them to known material spectra. Assigning each class a color and re-mapping the pixels geo-spatially creates a new color image (Short, 1999). Some pixels will remain unclassified because they do not meet the criteria of any class particularly well. In this case, they may be assigned to a class by way of statistical analyses. If the classification is supervised, an analyst can control assignment; otherwise, the computer can perform this automatically (Short, 1999; Sabins, 1997).

d. Summary

The major advantage of MSI is that the analyst can use the spectral characteristics of objects to aid in their classification. By doing so, he or she provides information about the area of interest that might not have been previously available in any other format. Using color encoding allows the analyst to coarsely classify soil vegetation types and water characteristics. Like infrared and radar formats, MSI provides information outside the range of the human eye.

On the other hand, MSI is a complex medium requiring expert knowledge in all of the electromagnetic regions described so far, as well as an understanding of how to properly manipulate the data. Digital storage and processing requirements increase with MSI, because each uncompressed scene contains one image per band. Provided the data is collocated with planners and manipulation tools exist, this is not a problem.

However, the limited data rates that shipboard planners have access to make it difficult to transfer a complete scene electronically.

2. Hyperspectral Images (HSI)

The distinguishing feature between MSI and HSI is the number of bands. While MSI sensors utilize up to seven spectral bands, SI sensors generate hundreds of narrower spectral bands in a spectral region (Aerospace Corp., 1998). Figure 7 pictorially displays the spectral difference between MSI and HSI for a typical portion of the electromagnetic spectrum (MUG, 1995).

The data returned by hyperspectral sensors are usually referred to as a hyperspectral "data cube," such as the one displayed in Figure 15. Two of the three cube dimensions are spatial coordinates (e.g. x, y) and the third dimension is wavelength λ (Aerospace Corp., 1998). Therefore, a single (x, y, λ) value describes the spectral response for position (x, y) at wavelength λ. Fixing the spatial coordinates in a scene on a single pixel, then plotting the extracted reflectance data as a function of wavelength produces a pixel vector. This trace is similar to the spectral characteristic curves in Figure 6 (Stefanou, 1997).

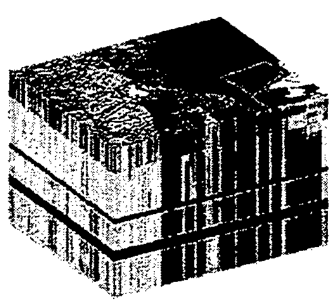


Figure 16. Sample Hyperspectral Data Cube (From Short, 1999)

The data cube may also be manipulated to produce monochromatic or color composite images, which can be interpreted literally. In addition to the literal techniques, there are also non-literal techniques that can be used to extract information from the data cube.

a. Non-literal Processing Techniques

The higher spectral resolution provides the opportunity to detect subtle spectral differences that are too narrow to be differentiated using MSI (MUG, 1995). These differences in reflection curves are not resolvable using the literal analysis techniques using panchromatic imagery (Short, 1999). Principal Components Analysis— which was discussed in the multispectral section— Spectral Angle Mapping, and Spectral Matched Filter are three basic non-literal interpretation techniques used on hyperspectral data cubes. Stefanou (1997) provides a more in-depth description of additional HSI processing techniques.

SAM and SMF were performed on hyperspectral data of a cove at Eglin AFB, FL. Figure 17 is a true-color composite of the cove, which is provided to orient the reader to the region. The target spectra selected from the data cube were (color coding in parenthesis): vegetation (green), shadows areas in vegetation (red), deep water (blue), shallow water (yellow), sand (brown), and asphalt (maroon). The spectral library of Figure 18, which was used to analyze the rest of the dataset, were developed by selecting pixels that were comprised of that target material from Figure 17. Figure 19 shows the pixels selected to produced the library overlaid onto the second principal component image (PC 2) for the data set.

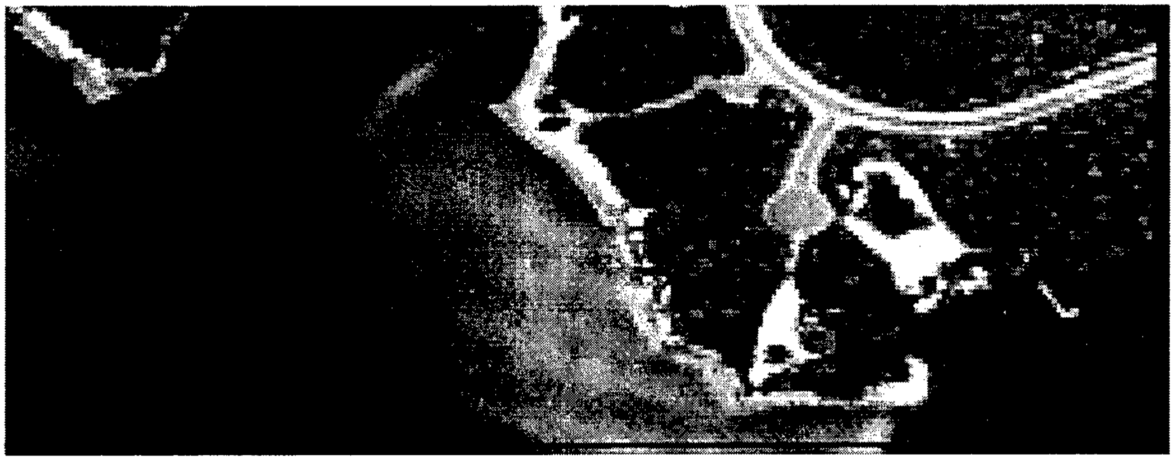


Figure 17. True Color Composite of Eglin AFB (Thanks to Chris Simi, Night Vision Lab)

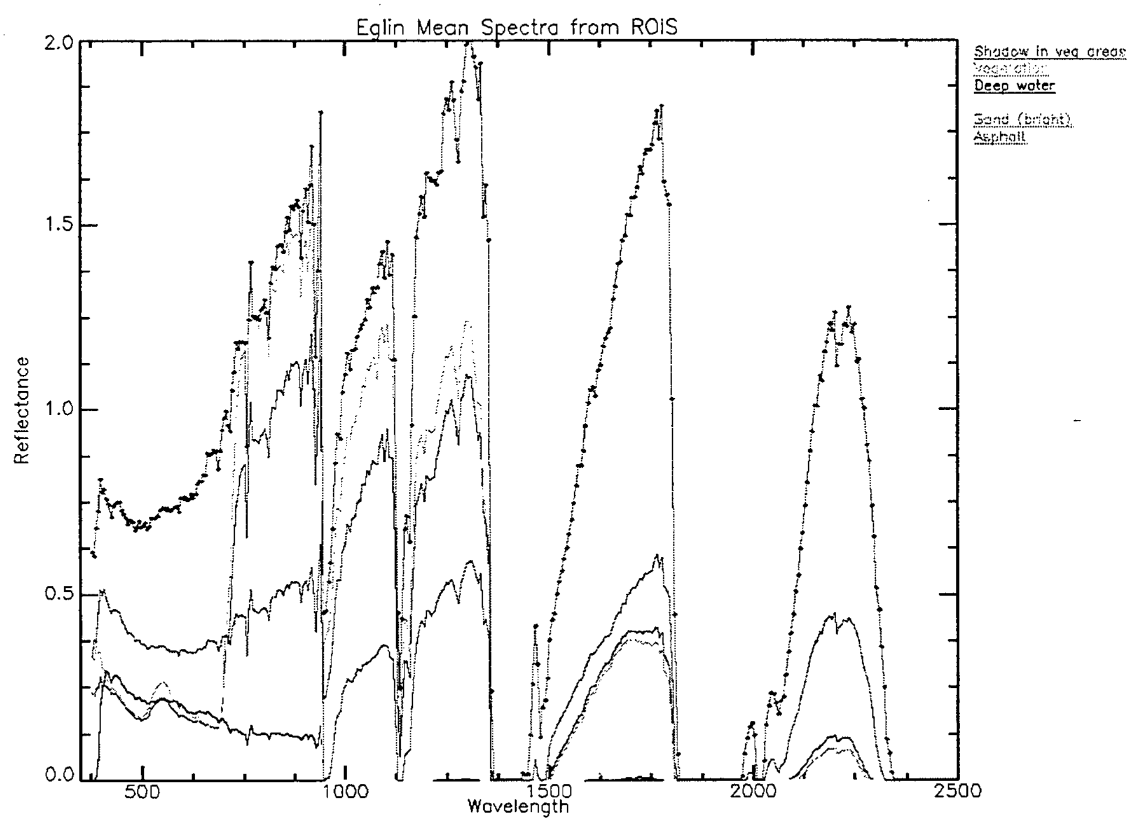


Figure 18. Mean Spectra for Regions of Interest

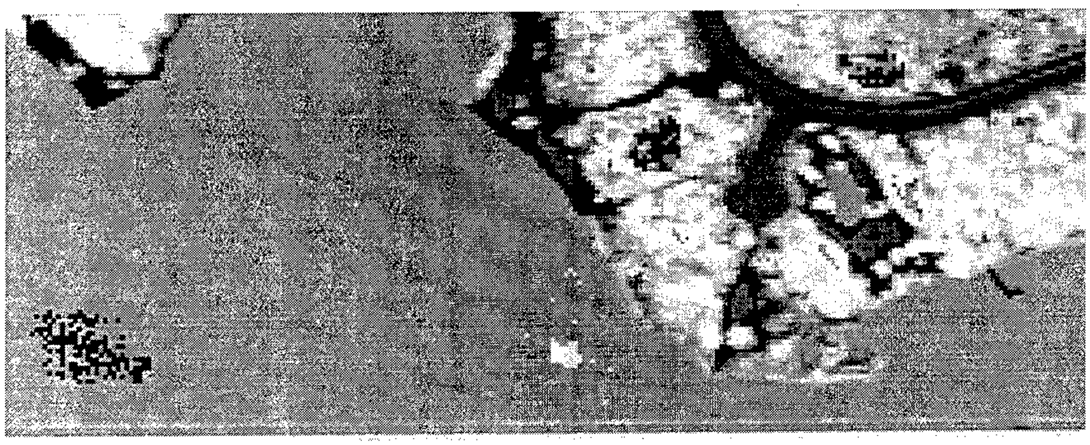


Figure 19. Regions of Interest for Classification Overlaid on PC 2

(1) Spectral Angle Mapping (SAM). SAM is a deterministic matching algorithm that compares pixel spectra to selected target spectra by comparing the angle between pixels when both are mapped into N-dimensional space (Richards, 1999). When the angle value is within a user-defined range (expressed in degrees or radians), the pixel is identified with the material that has those characteristic spectra. A composite image can then be created where the different elements in a scene are color coded, providing a material or target map. Figure 20 is an target map produced by performing SAM on the data set. The selected angle value was 0.1 radians. Increasing the angle value could have reduced the number of unclassified pixels. However, increasing the angle value also increases the chance of mislabeling a pixel.

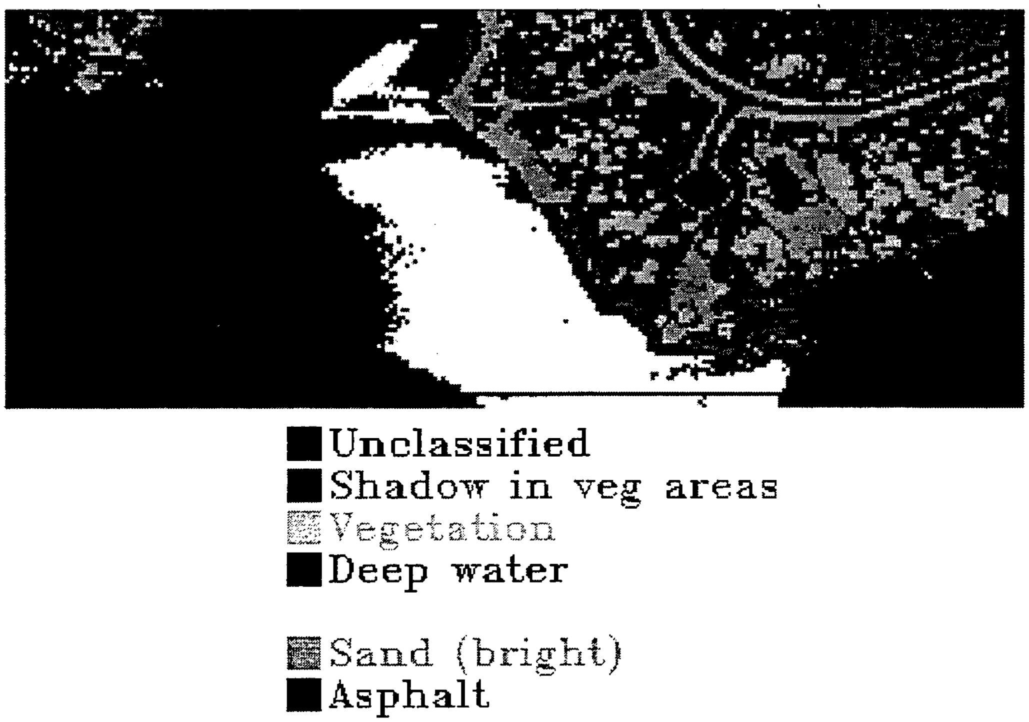


Figure 20. Target Map of Eglin AFB Produced by SAM

(2) Spectral Matched Filter (SMF). SMF is a technique that is representative of a class of statistical methods. It is derived from signal processing theory (Richards, 1999). SMF produces an output that is proportional to an estimated contribution of a target material to a given pixel (Collins, 1996). It is important to note that both SMF and SAM require a comprehensive spectral library for the analyst to conduct a comparison of the portions of the scene (Richards, 1999). Figure 21 illustrates the image produced from SMF. Brighter pixels indicate a better likelihood that that pixel is comprised of the target spectra. These individual SMF images can also be combined into color composites. Figure 22 is a SMF color composite produced by assigning the deep water image to the color blue, and assigning the shallow water to the colors red and

green. In addition, the SAM data for vegetation, sand, shadow areas around vegetation, and asphalt were over overlaid onto the image.

Figure 21. SMF- Vegetation Class Probability

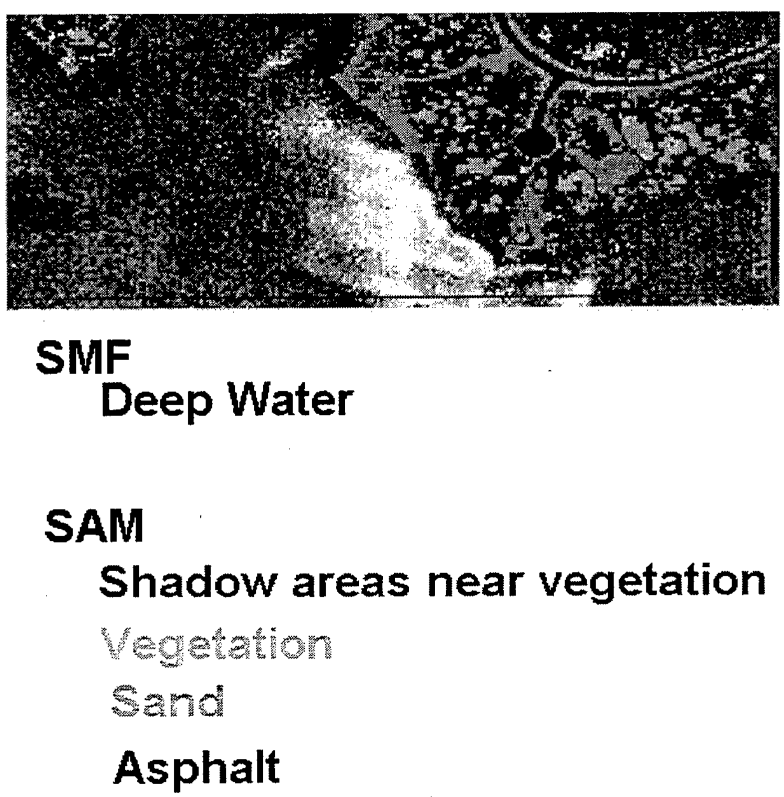


Figure 22. SMF Color Composite with Selected SAM Data Overlaid

b. *Interpretation Challenges*

A new set of problems arises when the analyst literally interprets a three-band HSI composite or the products of one of the exploitation techniques described above. The usage of false color images as with MSI is exacerbated because there are no "standard" composite images in HSI (MUG, 1995). In addition, when the analyst selects three portions of the spectrum for analysis, he or she in effect omits all but those three portions in the interpretation, thus negating the benefits of higher spectral resolution.

Analysis of spectral imagery is a discipline that is still under development, and there are a number of problems with the use of such data. Deterministic techniques require a complete spectral library of background and target materials. Statistical methods can distinguish materials, but may not identify them. Techniques such as SMF can extract targets from a background but produce images that give probabilities of occurrence that can be difficult to interpret (Stefanou, 1997; Short, 1999).

c. *Incorporating HSI into Existing Capabilities*

While HSI technologies have found applications in the commercial sector (Neuenschwander, 1998), such as in the environmental monitoring function, they are still not an operational capability within the US Department of Defense. However, HSI is considered an advanced technology concept, covered under the Common Spectral MASINT Exploitation Concept (COMSEC). The COMSEC's purpose, as stated in the Joint Warfighting Science and Technology Plan (1999) is quoted below:

"...to demonstrate COSMEC, end to end, to an operational user, showing the tactical utility of MASINT spectral analysis to the warfighter. This ACTD will establish COSMEC's ability to support the *Joint Vision 2010* mission areas of Information Superiority and Combat Identification, as well as supporting specific operational requirements. It will provide processing and exploitation capability to analysts in preparation for government and commercial multi/hyperspectral collection platforms. COSMEC supports both tactical and strategic intelligence using state-of-the-art MASINT processing and exploitation algorithms. These algorithms will enhance the U.S. spectral data exploitation capability. COSMEC has the ability to support a variety of operational requirements, including detection and ID of camouflage and vehicles, search and rescue, terrain characterization and mapping, beach route preparation, submarine detection, and detection of chemical/biological weapons. COSMEC will provide operational units with the capability to exploit data from existing and planned spectral sensors like the Land Remote Sensing Satellite (LANDSAT), Satellite Pour d'Observation de la Terra (SPOT), Senior Year Reconnaissance System Preplanned Product Improvement (SYERS P^3I), Hyperspectral Digital Imagery Collection Experiment (HYDICE), Spectrally Enhanced Broad-band Array Spectrographic System (SEBASS), Moving Target Indicator (MTI), and Littoral Airborne Sensor Hyperspectral (LASH). The modular design of COSMEC will simplify the process of updating the program with new algorithms or sensors, such as Warfighter and Naval Earth Map Observer (NEMO). This demonstration of COSMEC to an operational unit will establish the ability of multi/hyperspectral analysis to support search and rescue or camouflage detection in a combat-oriented mission. COSMEC's user-friendly interface and extensible architecture make it a versatile and useful tool for the warfighter."

3. Sensor Fusion

The final method of analysis involves merging data from two or more of the formats previously described to produce a separate image for the area of interest. When formats are combined properly, the analyst is able to extract more information about the area of interest than by using any of the formats separately. A typical format combination is MSI and panchromatic. LANDSAT color composites have poor GSD (30

m) but are good for classifying vegetation. Similarly, a good panchromatic image from SPOT or IRS has better spatial resolution but only for a single wavelength region. By digitally combining the panchromatic image with the color composite, the analyst can describe the region with panchromatic with its better GSD, as well as classify soil types using MSI, using a single image (Sabins, 1997).

Another example combines MSI and DTED to determine what pieces of land are feasible for a particular type of military operation. For example, an airborne drop zone must be flat, clear land. The analyst determines suitable locations by combining digital terrain elevation data (DTED) and MSI. By using MSI, the analyst finds areas devoid of vegetation, then uses DTED to determine the terrain gradient. Areas that meet both criteria are identified as suitable drop zones, which can then be included in the planning process (Gorski, 1999).

While sensor fusion shows promise, these are special products produced on demand and not used by military planners on a regular basis because of the lengthy process necessary to create a single image. Multiple formats for a single area must be located before they can be combined. After the individual images are acquired they must be co-registered. Common geographic points must be selected to properly align the images (Short, 1999). Co-registration in itself can be difficult because of the way objects layover in different formats (i.e., objects in radar lie towards the focal point, but objects in panchromatic lie away from the focal point) (Sabins, 1997). Completing this process in a timely fashion poses difficulties to afloat planners with limited bandwidth and computing power. In addition, these products will probably be displayed in false color.

As with MSI, the utility of the final product is based on how well the planner understands the basis for the analyst's assessment.

E. SUMMARY

This section reviewed the major planning aid formats used to prepare military operations. Each format has its absolute strengths and weaknesses, as well as advantages and disadvantages relative to other available formats. In most cases involving imagery, the planner's confidence in the analyst's assessment is largely based on his or her ability to understand how the analyst reached a decision.

V. THE STUDY

To determine the impact that HSI can have on amphibious warfare planning, the impact that existing formats have must be ascertained. The impact that existing formats have is evaluated by a study of image analysts. In order provide the analyst quantifiable jobs that they can perform on an image that support amphibious mission planning, a task analysis was performed on the amphibious planning process.

A. TASK ANALYSIS

A task analysis reduces a complex evolution into a set of less complex events that may be analyzed independently. The elements identified in the task analysis represent the information requirements necessary to plan the mission. This thesis uses the task listing method that Zemke (1984) describes to complete the task analysis.

Task listing captures the duties involved in performing a task by breaking a large task, such as planning an amphibious mission, into the primary subtasks involved with accomplishing the main task. Subtasks comprise the steps necessary to complete the main task regardless of the effort required for completion. In turn, the primary subtasks are decomposed into their subtasks in the same manner as the main task was. This process of subdivision is then recursively performed on each subtask until the desired level of granularity is obtained, which for this thesis was whether the subtask was answerable from Imagery Intelligence (IMINT). Subtasks that were not answerable by IMINT were omitted from further development following identification. This list of subtasks or task elements is provided in Appendix B.

B. IMAGERY ANALYST STUDY

The image analyst study was conducted to identify the cognitive processes involved with image interpretation in support of amphibious operations. Analysts were tasked with completing one of the task elements in Appendix B while being observed. In addition, this thesis looked to identify situations where the analyst was uncertain with his or her interpretation.

1. Participants

The imagery analyst study was conducted at two of the Unified Combatant Commanders Intelligence Centers, Atlantic Intelligence Command (AIC) in Norfolk, VA and Southern Command Joint Intelligence Center (SOUTHCOMJIC) in Miami, FL, as well as the Naval and Marine Corps Intelligence Training Center (NMITC) in Dam Neck, VA. The six subjects at AIC were assigned to the Expeditionary Warfare Products Division (DI3). The fourteen subjects studied at USSOUTHCOM were assigned to the JIC Imagery Division. The three subjects studied at NMITC were Imagery Analyst 'C' School instructors. The sixteen male subjects and eight female subjects were military image analysts from all of the services in the US DOD or DOD Civilians. The average exploitation experience was 7.4 years (range 1-20 years, S.D. 6 years). The average length of formal training for the 24 analysts was 11 months (range 3-48 months, S.D. 11.6 months). Data regarding age were not collected. Table 4 shows the rank and service of the different analysts observed in the study.

Rank	USA	USN	USAF	USMC	DOD CIV
E-4	1	2	1	0	-
E-5	3	1	0	2	-
E-6	2	5	1	1	-
E-7	0	0	1	0	-
CIV	-	-	-	-	3
TOTAL	6	8	3	3	3

Table 4. Image Analyst Study Demographics

2. Apparatus

Subject interviews were conducted in their work settings while performing their normal analytical duties. Analysts exploited high resolution panchromatic, radar, and IR littoral scenes derived from National Sensors. MSI from LANDSAT was also exploited. The author had no control over the image area, format, or quality presented to the analyst. At the JICs, the analysts performed their analysis on recently acquired digital images displayed on computer screens. At NMITC, the analysts performed their interpretation on hardcopy black and white photographs or acetate negatives using a light table. These images were specifically selected for training new analysts.

3. Procedure

During the interview each subject was asked how he or she would complete one of the subtasks provided in Appendix B. Subjects were free to use any available image formats and resource materials such as recognition guides. No time restrictions were imposed on the subjects. Interviews lasted approximately 40 minutes.

Information regarding the decisions were collected using verbal protocols (Carswell, 1999), in which the subject verbally described the steps taken to reach a cognitive decision based on what he or she perceived in an image. Verbal protocols were used because many of the intermediate steps in image interpretation are second nature to the subjects. This technique allows the interviewer to collect data by having the subject "talk through" a specific task. Finally, the author asked each subject how confident he or she was with his or her result. If they expressed uncertainty, subjects were asked to describe how their certainty level was reduced.

C. ANALYSIS

The data collected at this point was a list of task elements from the task analysis and human factors data describing how trained analysts interpret the most common forms of imagery. Qualitative analysis was performed on the data because the small sample size and the lack of control the observer had over the situation prevent analysis by statistical means. A written description of how an analyst accomplished a particular subtask was created. Each subtask description contains information about visual clues, identifiers, techniques, formats used, and level of certainty.

It is hypothesized these data will expose areas where the analyst is less certain with the answers provided to particular task elements. It is also hypothesized that data from HSI can improve the analysts' certainty in these area and possibly provide valuable information that was previously unavailable. The improved environmental knowledge

base will increase the mission planner's situational awareness in the littoral, allowing the creation of a better mission plan.

D. LIMITATIONS

While this study does have merit because it was conducted on image analysts performing tasks pertinent to amphibious warfare, there were weaknesses associated with its design. Specifically, the data collected, specificity, and the lack of control are all noted as limitations.

1. Data Collected

One type of data that should have been specifically collected during this study pertained to the analyst's relative certainty levels for different image types used to complete a particular subtask. While it is suspected that the user would still be most certain with results derived from high NIIRS panchromatic, this sort of data might have provided additional insight as to what in formats other than panchromatic makes the analyst uncertain.

2. Specificity

This study was focused on analysts supporting amphibious warfare. The results from this study were then extended to planners preparing amphibious missions. The benefits of exploring this single area in so much depth limits extension of the results to a larger unstudied population.

3. Observer Control

The author's lack of control over the situation was a limitation: there was a great deal of variability associated with image quality. A more controlled study could have been created by using having the analysts all interpret the same littoral images, which would have reduced some of the variability in the study based on image type and quality. Analysts could have accessed these hypothetical images via and INTELINK web page at the Naval Postgraduate School. Once they accessed these electronic images, they analysts could perform their literal interpretation.

VI. RESULTS

The first hypothesis — that there would be certain task elements for which the analyst would be less certain with their results — was validated. These task elements included: beach egress points determination, obstacle identification, surface characteristic determination, determining avenues of approach, underwater obstacle identification, and mobile orders of battle.

The specific task elements that were not observed include: key terrain identification, terrain effects on supporting arms; general climatic description; underwater gradient in the vicinity of the landing site out to the three-fathom curve; average sea-state determination; mobility corridor determination; rail network determination; availability and condition of the civil/military telecommunications network; and avenue of approach determination for ground or fixed wing air forces.

Table 5 shows what formats analysts used to complete a given task during the period of observation. More precise numbers cannot be given in the table because the specific number of images that an analyst used during the interview was not noted.

Task	Panchromatic	Radar	Maps	MSI	IR
Coastal Configuration	X	X			
Beach Egress Points	X				
Obstacle Identification	X	X			
Cover and Concealment Determination			X	X	
Surface Characteristic Determination	X			X	
Determining Avenues of Approach	X		X		X
Tidal Condition Determination	X				
Determining the Nature of the Surf	X				
Wind Condition Determination	X				
Determining Water Currents	X				
Underwater Obstacle Identification	X		X		
Road Network Characteristics	X				
Inland Waterways Characteristics	X				
Static Order of Battle	X	X			X
Mobile Orders of Battle	X	X			X
TOTAL	14	3	3	2	3

Table 5. Counts of Image Formats Used by Analysts

A. GENERAL TOPOGRAPHIC DESCRIPTION

1. Coastal Configuration

To characterize the coastal configuration, the subject first located the large water mass by its darker color in either the panchromatic or radar image format. He or she then moved toward the land by identifying the breakers, which appear as long thin white lines on the dark background. After identifying the coastline, the subject selected portions of the beach for further study in order to determine if they met the criteria of a possible landing site. The factors impacting the selection at this point include the expected size of the landing force, the type of landing craft used in the operation, and the beach size and shape. The first two factors were facts that are available to the subject. Possible landing areas are classified initially by their shape— straight, concave, or convex —then by measuring their physical size, and finally determining the geographic coordinates for the beach center. The subjects did not identify any uncertainty regarding this task.

2. Beach Egress Points

With possible beaches initially identified, the subject used the panchromatic images to determine if that area has adequate points for the landing force to exit the landing area from enroute to the objective. Adequate egress point descriptions included information regarding location, exit type, beach relief, and soil composition. The subject detected potential exits from differences in tone, which are either lighter or darker than the background. Depending on the degree of randomness that an exit exhibited, the subject classified the exit type as either manmade or natural. Natural exits exhibited

better blending into the background while the manmade exits displayed geometric, repetitive patterns. The subject was less willing to describe relief data from a single image. Therefore, he or she also analyzed topographic maps to make these determinations. The narrowest point of each exit was measured to provide the planner a measure of how easily an exit could be sealed by the defender. The three beach-soil classifications an analyst was confident in making were sand, pebbles, and rocks, which is a determination based on image texture and pattern. The subject exhibited uncertainty in making a more refined classification.

3. Obstacle Identification

The subject located manmade obstacles that were not buried by their shape and repetitive placement on the ground in either the radar or panchromatic image. Obstacles whose construction material was metal were detected on radar, even if the obstacle was not detected in panchromatic. Buried objects such as mines could possibly be detected because of ground discoloration, but the subject stated he or she would be uncertain regarding detection if the time between object burial and imaging was too long. The subject located natural obstacles such as rocks, inland streams, etc. by understanding how they can influence ground force movement. Inland streams are a darker color than the background and have a natural shape. The subject did not describe how other natural obstacles were detected, nor did he or she express uncertainty categorizing these features.

4. Cover and Concealment Determination

In order to determine cover and concealment effects, the subject used a topographic map of the area. However, maps are of varying quality and the older the data on the map, the more the subject relied on other formats such as MSI. Non-gray scale, color composite maps were created for the area of interest. For areas with great seasonal variation in foliage, the subject ensured that the source image was from the same season as the operation execution. The subject selected the bands to best describe the level that the terrain provides protection from enemy fire (cover) and concealment from enemy forces. There was no standard color scheme used. However, the subject emphasized that he or she must make the color representation simple enough to be able to explain it to the commander. The subject did not express uncertainty in making this determination.

5. Surface Characteristic Determination

Both panchromatic and MSI were used to characterize the soil composition. The subject needed to make cognitive decisions about soil composition, drainage, and relief.

For the panchromatic format, the subject could only classify beach soil as either sand, pebbles, or rocks based on their texture and pattern. The subject did not comment on soil characterization other than near the beach. The subject made soil drainage characterizations based on color, because areas such as streams and water-saturated land appear darker in the scene. A computerized version of stereoscopy produced a qualitative description of vertical relief using two panchromatic images. The subject exhibited uncertainty in making specific soil characterizations using panchromatic.

The subject used MSI color composites to characterize soil composition. Beyond band selection, the subject did not quantify how this was performed. The subject did not quantify how precise a characterization he or she could make from the presented image for either the beach material or the soil composition of the area immediately behind the beach. The subject used digital terrain elevation data (DTED) and the elevation data on hardcopy charts to characterize surface slope. The subject did not express uncertainty performing this task using MSI in conjunction with the elevation data.

6. Determining Avenues of Approach

Subjects in the study performed two tasks that are relevant to determining the avenues of approach for rotary wing forces, locating power lines and determining suitable helicopter landing zone locations (HLZ). Using a topographical map, the subject located power lines by their symbol and also located the nearest prominent feature. Then the feature was located in an IR image and the subject performed a localized search for the first tower. The tower was located by either looking for the tower directly or by locating the shadow it projected. The subject re-centered the image at periodic intervals where he or she thought the next support tower would be located. The subject was not certain they could locate all the power lines in a scene.

In determining potential HLZ's, the subject scanned the panchromatic scene's wide-open grassy areas such as a golf course or athletic field because they generally have a flat slope and fewer power lines surround them. The subject then determined the size and shape of the potential landing spots. He or she did this by examining the boundary

between the soil comprising the landing spot and surrounding features such as trees or fence line. The subject used an independent format such as a topographical map or DTED to determine the terrain slope of the landing area. The subject also recommended an approach path based on prominent navigation features such as buildings. After determining the size and shape of the actual landing area, the subject searched the landing area and the approach path for flight hazards such as power lines or lamp poles using the method described in the previous paragraph. Then the analyst looked for access points on the ground such as a road network. Finally, the subject performed an area search for air defense equipment, military units, and medical units.

Dense urban areas and threat condition added uncertainty to locating adequate HLZ. In addition, the subject expressed uncertainty in locating all flight hazards such as power lines and poles.

B. GENERAL HYDROGRAPHIC DESCRIPTION

1. Tidal Condition Determination

The subject estimated the tidal conditions by comparing panchromatic images at high and low tides. A measurement of the distance from the water's edge at low tide to the point high water line was made. The high water line was identified by the shading difference between the darker water-saturated sand and lighter dry sand. A potential landing site could be discounted if that measured difference was too great, because the lack of cover and concealment place the landing force at a higher risk. The subject also

compared the two images looking for differences such as obstacles that might be covered at high tide. The subject did not express uncertainty regarding this task.

2. Determining the Nature of the Surf

The subject determined the nature of the surf by making two measurements on the panchromatic image. He or she first measured the distance from the water's edge to the point where the surf first breaks, then measured the angle that the waves strike the beach. These measurements provide an indication to planners of how dangerous the surf is to landing craft and personnel. The subject did not express uncertainty regarding this task.

3. Wind Condition Determination

The subject estimated the wind condition by analyzing wave action using panchromatic images. The subject estimated wind direction to be orthogonal to long, thin, white lines that characterized the waves. Larger waves also indicate stronger winds. The subject analyzed the waves more carefully to determine whether the wind was blowing on or off shore. If the leading edge of the wave is clean (i.e., no water spray) the wind direction was blowing to sea. Otherwise, the wind was blowing onto land. The subject did not express uncertainty regarding this task.

4. Determining Water Currents

The subject estimated water current by analyzing sediment deposit on the beach using panchromatic imagery. The sediment was identified in the image by the variation

in texture between it and the other beach materials at the water's edge. If the sediment deposit appears evenly distributed across the beachfront, the current runs directly into the beach. If the sediment collection was uneven, then the current runs orthogonal to the area with more sediment.

In addition, the subject used the position of manmade objects such as breakwater and jetty if available to judge the water current direction. The water current will hit the breakwater first and deflect into the jetty in order to keep the sediment outside a channel. The subject did not express uncertainty regarding this task.

5. Underwater Obstacle Identification

The subject stated that offshore obstacles could show up in panchromatic imagery if they are at a depth shallow enough to affect surface wave action. Using a low tide image, the subject scanned the wave pattern for line breaks away from shore. More random breaking patterns can indicate point obstacles such as rocks, while uniform breaking patterns indicate possible sandbars. The subject expressed uncertainty in locating deeper underwater obstacles because those obstacles that did not break the water surface or affect the wave action would not appear in the image. The subject stated he or she would also review hydrographic charts. In order to locate known underwater rock formations.

C. TRANSPORTATION FACILITIES DETERMINATION

1. Road Network Characteristics

The subject assessed the military utility of road networks by their type, width, and construction material. The subject first identified roads by their long narrow shape. The gray scale shade of the road in the panchromatic image is an indicator of the construction material: dirt roads blend into the background, concrete appears light gray, and asphalt appears very dark. The number of entrances and exits to the roadway per unit distance were enumerated. In addition, the subject examined the terrain relief surrounding the road for potential choke points such as tunnels and bridges. The subject did not express uncertainty regarding this task.

2. Inland Waterways Characteristics

The subject used gray scale shade and shape differences to identify inland waterways. The subject stated that streams and riverbeds were darker than the surrounding background in the panchromatic image. In addition, the subject stated that the topographical maps did not completely describe inland waterways. The subject attempted to classify the waterway as manmade or natural based on how random or repetitive the waterway appeared in the scene. The subject also measured width at various points. The subject did not express uncertainty regarding this task.

D. ENEMY MILITARY SITUATION DETERMINATION

The techniques used by subjects on panchromatic, radar, and IR images for determining force strength and disposition varied between static and dynamic orders of battle. Static orders of battle include electronic, missile, air, naval (in-port), industrial, and ground forces in garrison. Dynamic or mobile orders of battle included any dispersed force such as deployed ground forces or forward air bases. The subjects stressed that knowledge about the sensor and the enemy as well as analyst experience aided the exploitation process. They also stated that shadows could help or hinder exploitation. Shadows were beneficial for seeing features too small to be captured by the sensor, but over-elongated shadows could distort information, possibly leading to misidentification. When discriminating between classes of objects, subjects would use key recognition features or length-to-width ratios as an aid.

1. Static Order of Battle

In previously identified sites, the place's function was already known. In this instance, the subject was primarily interested in updating the body of knowledge about the site. The subject used existing knowledge about a site, either other images or reports based on prior interpretation, to aid in completing the task. Radar, IR, and panchromatic image formats all were exploited. As the subject scanned the site, he or she enumerated and classified different pieces of equipment.

The subject interpreted the scene using a variety of techniques to aid in object recognition. Equipment's general shape might provide clues as to the way it would

appear in a scene or the marks it might leave on the ground when it is removed. In addition, systems requiring extensive maintenance could have more support vehicles that could be detected on IR or radar. The subject also scanned images for known patterns based on the way certain systems were spatially arranged. More specifically, the subject looked for regular patterns on a random background. Ground shadows were also used to aid in identifying key recognition features. Finally, relative size between unidentified objects was used to help classify objects. The subject also added that high NIIRS panchromatic imagery was better than a map, especially in the urban areas. This was because the map could not adequately capture the complexity of the scene. The subject analyzed overgrowth to determine the frequency of usage for an unoccupied site. The subject did not express uncertainty regarding this task.

2. Mobile Orders of Battle

The subject stated that mobile orders of battle such as dispersed troops were more difficult to locate than their static equivalents. He or she attributed this to the relatively limited baseline knowledge that could aid in the search, sometimes only geographic coordinates. For this worst case scenario, the subject electronically plotted the coordinates on the image and began a wide area search. The subject scanned areas closer to lines of communication such as roads, trails, and rivers before searching other areas. The subject searched these areas for known geometric patterns that could indicate the function of a site. Terrain configuration significantly impacted the subjects' ability to

identify units or equipment. For example areas with dense vegetation or significant terrain relief were particularly difficult to locate targets of interest.

In cases such as a ground unit departing garrison, the subject first searched known training areas for the missing units. Confirming their presence in these areas could be an indication of routine operations. The subject also stated that some units modified their operations in the field, so he or she looked for these differences to locate units. If the subject successfully located one piece of equipment, he or she would search the area for other equipment associated with that unit. The subject also estimated unit size by enumerating objects that could be located, then taking the difference from what a unit doctrinally deploys. The subject expressed uncertainty regarding this task.

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VII. DISCUSSION

This thesis approaches the task of determining the potential impact of HSI in amphibious planning using the following process. The first section provides an explanation of how analysts and planners interpret planning aid formats using visual information processing theory. In addition, it offers a possible explanation for why the false color format is disturbing to planners and analysts. Having established this, a method for HSI exploitation and interpretation are developed. Then the work of Delgrand (1993), Fay (1995), Collins (1996), Bergman (1996), and Stuffle (1996) are briefly presented as examples of where HSI can provide valuable information in areas where the analyst is uncertain. Finally, after establishing how the interpreter acquires better information, particularly in areas of uncertainty, the effects of planning an amphibious mission with an improved knowledge base are evaluated.

A. INFERENCES FROM RESULTS

The objective of this section is to explain how image analysts cognitively process the different image formats using visual information processing. This is accomplished by developing a processing model that is based on the literature review and the results of the study. The model is then extended to include planners. From the model, a possible explanation for why false color formats are so disturbing to planners and analysts is provided.

1. Explaining Image Interpretation Using Visual Information Processing

The model that is developed in this section takes the form of a sequence of events that the analyst attempts to complete in order to fulfill a subtask. Distinct variations in other formats such as radar and MSI are accounted for after establishing the initial model, because the initial model is developed exclusively for the panchromatic format. Finally, methods that the analyst employed for reducing any certainty are reviewed.

a. Processing sequence

To complete a subtask, image interpretation seemed to follow a sequence, which is shown in Figure 23. The basic sequence for the panchromatic format starts with attempting to establish perceptual constancy. Then the analyst must find a starting point in the image and establish a search method, Next, he or she locates, then refines raw pieces of information. It is probable that to accomplish a subtask, the analyst must complete these intermediate steps several times before accomplishing the subtask. Finally, the analyst combines pieces of information in higher-order processes in order to fulfill the subtask. The confidence the analyst has in the end product has an associated certainty level.

Stimulus-based and knowledge-based processing are used by the analyst in varying capacities while completing this sequence. When the analyst is confident about the format being exploited and the task to be completed, it appears that the analyst employs knowledge not found in the stimulus. Therefore, top-down processing has a heavier emphasis. However, if the analyst was uncertain with the format or the task being

accomplished, he or she could not employ knowledge as effectively. In this case, stimulus-based processing had greater emphasis.

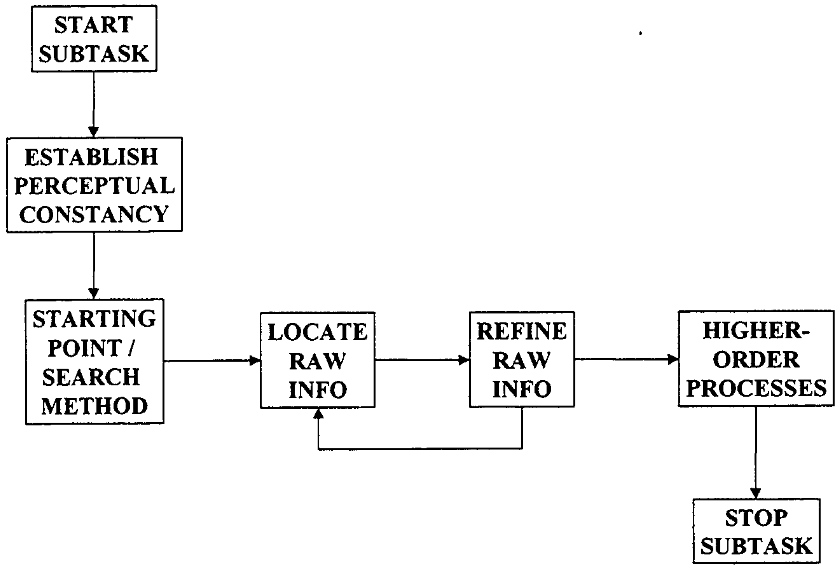


Figure 23. Flow Chart for Completing Interpretation

(1) Establishing Perceptual Constancy. Given that perceptual constancy can be considered a form of general knowledge, it is also the analysts' first attempt at top-down processing. If the analyst can establish perceptual constancy, which means that he or she has successfully stabilized the appearance of the image in the domains of shape, size and color, then it is possible that the analyst can employ other forms of general knowledge. This reduces the emphasis on stimulus-based processing. However, if the analyst is unable to effectively establish perceptual constancy, then he or she must probably rely on more heavily on stimulus-based processing.

There are several factors that affect how quickly and confidently an analyst can establish perceptual constancy for a remotely sensed image. To start, how well the analyst understands the image format itself is an important part of establishing perceptual constancy in all three domains (shape, size, and color), because the image properties (scale, brightness, tone, contrast, and resolution) vary for each format. Developing perceptual constancy is probably easiest in the panchromatic format because the analyst is continually establishing perceptual constancy with energy from this wavelength band as part of everyday experience. While the perspective varies from that which the analyst comes into contact with outside of work, experience aids the analyst because the he or she grows more comfortable viewing images with an overhead perspective and a variety of look angles. This experience aids in establishing size and shape constancy. In addition, the good spatial resolution found in panchromatic imagery allows shapes to be portrayed accurately, which appears to make establishing shape constancy easier. The need to establish color constancy was bypassed in most cases because the panchromatic images are displayed in gray scale. Consequently, perceptual constancy might have been easier to establish on these images because there is one less domain (color) to be stabilized prior to commencing the next step.

(2) Locating a Starting Point / Search Methods. Next, the analyst determines where in the scene to start searching for raw pieces of information. In cases where the initial site location was already known, the subject plotted the geographic coordinates electronically onto the image. When the site was not known, the subject

needed additional information to provide that focus. In most cases, a general geographic reference from other report types such as those from informants or electronic signals provided a geographical starting point.

With the initial point established, the analyst relies on learned techniques such as following lines of communication (roads, waterways, power lines, etc.) to locate pieces of information. Using techniques such as these are an indication that the analyst is employing knowledge not found in the stimulus to aid in processing. This results in the analyst reducing the search space without having to search the entire image. However, if a technique such as this cannot be employed, the analyst must emphasize stimulus-based techniques. During the study, analysts expressed uncertainty in performing wide area searches that have little cueing data.

(3) Locating Raw Pieces of Information. Identification of raw pieces of information is the first event in which the analyst draws something out of an image that an observer can also experience. The knowledge that the analyst uses at this point probably better fits the form of stimulus-based processing method such as feature theory.

The analyst probably locates the raw pieces of information by using the elements of recognition: shape, size, tone, texture, pattern shadow, site, and association (Campbell, 1996). To help the analyst draw the information out of the image, there would be qualifiers on the elements of recognition. For example, in the subtask "determine coastal configuration," the analyst must identify pieces of raw information

about the shape of a length of coastline. In this case, the analyst will use three different qualifiers to locate that particular length of coastline. He or she first finds the breakers by using specific instances of shape (long, thin lines) and color (white on a dark background). The specific instance of association (breakers are near the coast) are then used to determine the shape of the coast.

(4) Refining Raw Information. This step is significant in this process for two reasons. First, the refinement of raw information requires knowledge not found in the image for successful completion. As a result, it is better characterized in the top-down paradigm. In addition, it is also probably the first place where feedback to earlier steps can occur. For example, an analyst cannot start to search along a line of communication until that line of communication is properly identified.

To refine raw pieces of information, the analyst performs tasks that Campbell (1996) describes: classification, enumeration, mensuration, and delineation. Continuing the "coastal configuration" example, in order to generate a set of coastline areas suitable for landing, the analyst would measure portions of the "raw" coastline to determine which areas meet the minimum size criteria for landing a particular sized force.

(5) Higher-Order Processing. The analyst accomplishes the subtasks in this scenario by combining the refined pieces of information with specialized knowledge. In the "coastline configuration" example, the set of potential sites is perhaps rated by evaluating their shape (straight, concave, or convex) with respect to how the

enemy can concentrate firepower against the landing force and the known enemy troop locations. In this instance, the specialized knowledge would be an understanding of how different coastline shapes and troop disposition impact the placement of anti-landing defenses.

b. Interpretation Variations Based on Format

With the basic sequence established for the panchromatic format, variations in the sequence can be examined for the radar, IR, and MSI formats. This must be done because the basic image properties (scale, brightness, tone, contrast, and resolution) vary for each format.

(1) **Radar.** The major difference in the visual information processing sequence between radar and panchromatic appears to be in the refining raw pieces of information step. After the analyst selected a piece of raw information to interpret, he or she talked about how the sensor collected energy, explaining the geometry necessary to get an adequate return or how that geometry affected the analyst's ability to identify key features. For example, one analyst was trying to classify a warship in a crowded port, but the ships' rocking motion smeared the return from the target of interest. The subject identified the ship by first employing knowledge about that country's naval order of battle; this allowed the analyst to reduce the number of possibilities to three or four ships. Then he or she identified specific features on the ship such as approximate length and number and position of masts and gun turrets on the ship. These pieces of

information were then cross-referenced to a recognition guide to properly identify that warship. This example highlights the possibility that the analyst's difficulty in locating and refining raw pieces of information may be an indication that the analyst has to use specialized knowledge about the format sooner in the interpretation process. However, in other cases the analyst was not able to refine the information to the level of granularity that they could get from a good resolution panchromatic image (e.g., it was a transport aircraft, but he or she could not tell whether the aircraft was a C-130).

(2) IR. There did not appear to be any significant variations in interpretation for analysts exploiting IR images. However, the author only observed three IR scenes, which all appeared very similar to panchromatic images.

(3) MSI. One area where the author specifically tried to collect data was in the exploitation of MSI false color images. The primary question is whether the form of such a composite made interpretation difficult. In the two applications observed it was unclear whether the analyst established color constancy for the MSI format. The subject specifically stated that he or she was not trying to equate color to a particular object (e.g., blue water or green vegetation). Rather, the analyst was trying to identify potential regions (e.g., this purple shaded are is a void of vegetation). In other words, the raw pieces of information the subject collected were areas of a certain color. Information refinement in this case was accomplished by integrating overlaying DTED onto the false color composite and eliminating areas based on slope. The author is

reluctant to make further inferences about the visual information processing methods employed to interpret MSI given the extremely small sample size.

c. *Uncertainty*

When the subtask is complete, the analyst has a particular confidence level with the result of their interpretation. Some of the factors that affect this confidence level are the basic image properties such as resolution and contrast. When the analyst is less confident in a given subtask or with a image format, he or she is unable to apply the specialized knowledge of image interpretation. In this case, it is more probable that he or she will place a heavier emphasis on the stimulus.

However, the end user still needs the results of the analysts. As a result, subjects had mechanisms available, such as NIIRS Rating, supervisory check, sensor revisit, and older images, to increase the level of confidence they had in their judgments. The analyst informs the end user of their confidence in most first phase exploitation reports by reporting the image's NIIRS rating. The author is viewing the NIIRS rating as a level of confidence because the analysts should be able to draw more information from higher NIIRS images. In addition, another trained military analyst always reviewed the subject's work for errors. This involved the second analyst reviewing the image and the report produced from the image. Frequent sensor revisit and reports from other intelligence sources improved the subject's confidence in making judgment calls, particularly during radar exploitation. Finally, the subject used other sources such as older panchromatic images to improve confidence.

2. Visual Information Processing Employed in Planning

The visual information processing model is also applicable to planners, although it requires a slight modification in scope. While the analyst focuses on lower level products (i.e., answering subtasks), the planner is more focused on combining the results of subtasks such as coastal shape, enemy defense location, and obstacles to develop a situational awareness about the battlespace that is the foundation for the mission plan. After developing their situational awareness, they can employ the knowledge in the areas of tactics and weapons employment to develop the actual mission plan.

Planners probably have the skills to complete the basic visual processing sequence for the panchromatic and map formats. Panchromatic and map formats are singled out as "interpretable" to all planners, because the planner can easily understand the assessments from panchromatic with minimal explanation. In addition, the planner has received the necessary training to interpret maps as part of their military education.

Some planners such as Aviators and Targeting Officers may have additional experience with the IR format, because they use IR sensors such as night vision goggles (NVG) or forward looking infrared (FLIR) while conducting the mission. However, based on the author's experience, the Aviators' mission is still planned from panchromatic images and maps. So while the Aviator is flying the mission, he or she is comparing NVG / FLIR data to information previously acquired by the panchromatic and map formats.

However, other planners may have had even less experience with formats other than panchromatic and, as a result, be less likely to believe an analyst's assessment.

Wollenbecker (1999) commented that gray scale IR negatives were given a commander at one point in his career instead of the actual IR image, because the format looked more like a "photograph." The person's ability to process the image format, which is not panchromatic, is negatively impacted because he or she is expecting a photograph.

a. Why False-Color is Confusing

To illustrate why false-color are confusing, the first phase terrain categorization map of the KERNEL BLITZ 1997 data set in Figure 24 is used (SITAC, 1997). It confuses the analyst or planner because colors and textures used to represent objects might be associated in long-term memory with other objects. In the original image, there is a legend that describes the terrain categorization. However, the legend alone is insufficient because it does not reduce the internal confusion created by the color schemes in the image.

One example of this confusion is the region with the appearance of molten lava that represents ocean. If the author were trying to locate targets of interest such as waterborne obstacles, he would obviously look in the water region. However, when the author looks at the ocean in this scene, he perceives molten lava.

The internal confusion between whether he is looking at molten lava or ocean continues throughout the processing sequence. Initial attempts at top-down processing probably fail because the image violates color constancy (e.g., the water looks like molten lava and the land looks like water). While the author is able to locate the coastline, developing an effective search pattern for the water is difficult because there

are many textures in this portion of the scene. Consequently, the author has difficulty locating raw (or refining) pieces of information because the scene does not permit him to employ his knowledge about how to identify waterborne obstacles (i.e., looking for breaks in smooth water or in wave patterns). Therefore, the author would report to the planner that he could not locate any obstacles in the water and that he is very uncertain of his result.

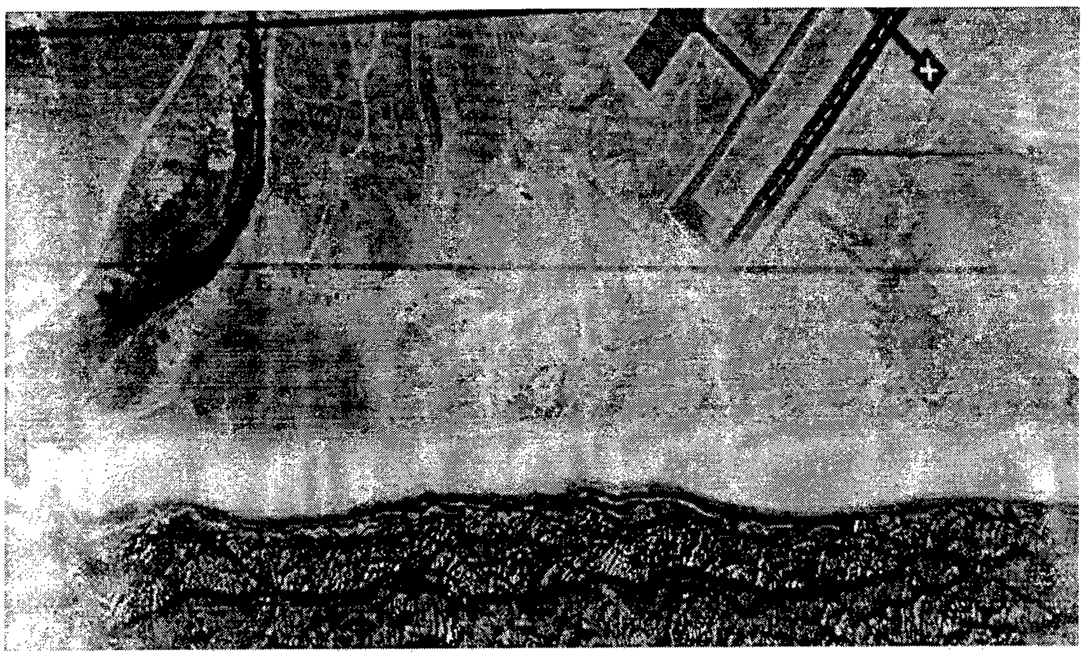


Figure 24. Terrain Categorization of KERNEL BLITZ 1997 Data (SITAC, 1997)

Therefore, based on the work of this thesis, a person's (analyst or planner) lack of training in false-color formats such as MSI and HSI prevent the effective establishment of color constancy. Without color constancy in these formats, people cannot completely establish perceptual constancy. In addition, they also have a more difficult time employing knowledge that they would otherwise use in image exploitation.

Consequently, they cannot complete the rest of the visual processing sequence efficiently, because perceptual constancy is the first step in the sequence. If the planner perceives that stimulus-based processing takes too long, he or she might find a more trusted format, even if the information is less accurate.

B. HSI EXPLOITATION

With a possible reason for why false color products such as HSI are confusing to planners established, it is possible to create a way to present these products to planners that minimizes problems with color constancy and subsequently to develop a methodology for exploiting HSI. This can be accomplished by the following: literal interpretation, non-literal interpretation, and presentation to the planner.

1. Literal Interpretation of HSI

Panchromatic images are the preferred image format by planners and analysts. They can be created from the HSI data cube by generating true color composites from the HSI data cube, then converting the resulting image to black and white. Figure 15 illustrates another method of producing a panchromatic-like image, which is the first principal component image of Morro Bay. Then the analyst exploits (or planner uses) these images using the same visual information processing sequence already employed on other panchromatic images. The raw or refined pieces of information derived from the data cube will build the context necessary to perform spectral interpretation on the

image. Therefore, HSI can provide both the analyst and the planner a baseline of information and products that they are most comfortable exploiting and using.

2. Non-literal Processing of HSI

With literal processing completed, the analyst can begin spectral interpretation. This involves applying a series of algorithms or transformations to the data cube and visually interpreting the results. Prior literal processing established the context for the scene. This allows the analyst to use the data set in such a way that they are refining pieces of raw information using non-literal means instead of drawing out raw pieces of information for the first time. This process was illustrated above for a littoral scene in Figures 17-22. To further illustrate HSI exploitation, a partial review of the Collins (1996) results from his analysis of the WESTERN RAINBOW data set. PCA and SAM are the techniques reviewed below. It is also important to highlight that the data set Collins analyzed extended into the thermal IR region.

a. Principal Components Analysis (PCA)

In general, the first PC image is the positive weighted average of all the bands analyzed. For a thermal sensor, this produces an output that appears similar to that produced by a forward-looking infrared (FLIR) sensor. One is shown in Figure 25.a (Collins, 1996). Planners such as Aviators and Targeting Officers who have previously worked with FLIR data should have the knowledge necessary to interpret the image. These people should be able to identify the man-made objects as well as potential

concealment areas in Figure 25.a even if the spatial resolution prohibits further refinement.

b. Spectral Angle Mapping (SAM)

A typical classification approach, illustrated in Figure 20, is the SAM technique. Application of this process to the thermal data produced the image shown in Figure 25.b. The information level of information in Figure 25.b is different from the simulated FLIR image in Figure 25.a. For example, spatial resolution and contrast in Figure 25.a are insufficient to classify the "X" shaped array in the lower half of the image as anything other than vehicles. However, the SAM classification tells the analyst or planner that the 'X' shaped array is a group of T-80 tanks.

One problem with the target map is that if too narrow of an angle value is chosen or too few spectra are used for comparison, much of the scene can remain unclassified. This results in much of the context in the original image being lost as a by-product of the analysis, ultimately making the SAM image more difficult to visually process. Luckily, context can be regained in this image by overlaying the target map onto a panchromatic image, as show in Figure 25.c. The image was produced in Microsoft Image Composer 1.5 after scanning Collins' base images into .GIF format. Overlaying is a standard feature in hyperspectral manipulation software such as Hypercube (Pazak, 1999). More importantly, the image in Figure 25.c provides better information than either Figures 25.a or 25.b do independently. In Figure 25.c the five blue boxes in a star pattern are an array of T-80 tanks, which are also not camouflaged or

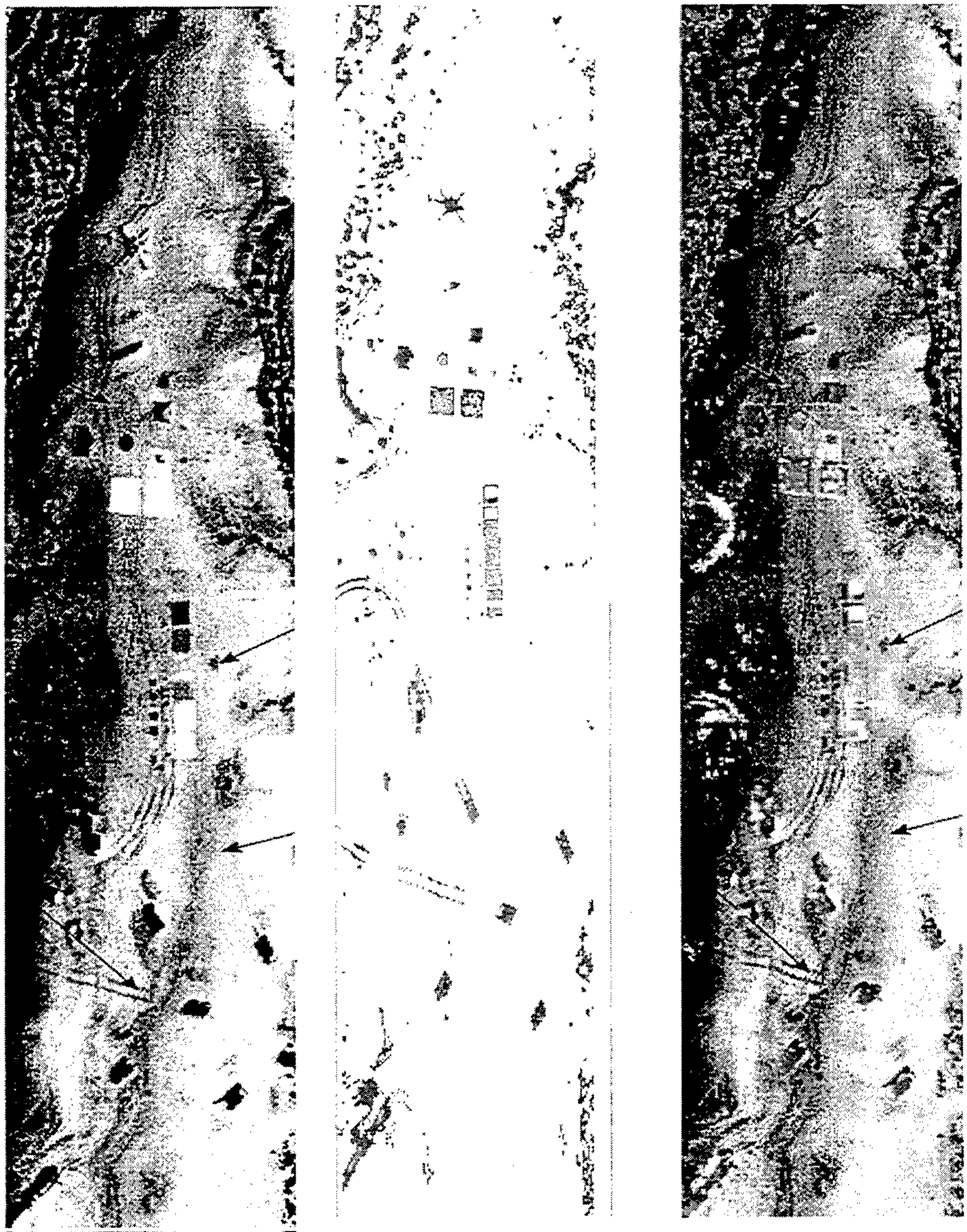
concealed in the terrain, making them easier to identify. Based on the author's experience, it is speculated that planners might feel the same way.

3. Presentation to the Planner

An HSI-derived intelligence package that is delivered to the planner should include panchromatic images, post-algorithm images, and written descriptions. Panchromatic images allow the planner develop the baseline for the area. Post-algorithm images are used to supplement the information already derived from the panchromatic image. As the planner is unfamiliar with the color schemes used in hyperspectral formats, one-paragraph narratives of what the colors describe should be accompany each of the post algorithm images. The narratives allow the planner to effectively combine the general knowledge of the area that the panchromatic image provides with the specialized knowledge from false color HSI products in the planning process without extensive training in HSI.

C. MATCHING HSI CERTAINTY WITH ANALYST UNCERTAINTY

If analysts and planners have established methods to perform subtasks and they are confident in the results, then they are unlikely to accept or develop a different procedure using a different format to get the same result. However, they might be more willing to accept methods to gain intelligence in areas where they are currently uncertain. Mine detection, bathymetry, and target detection are three areas where spectral analysis shows promise.



a. Simulated FLIR

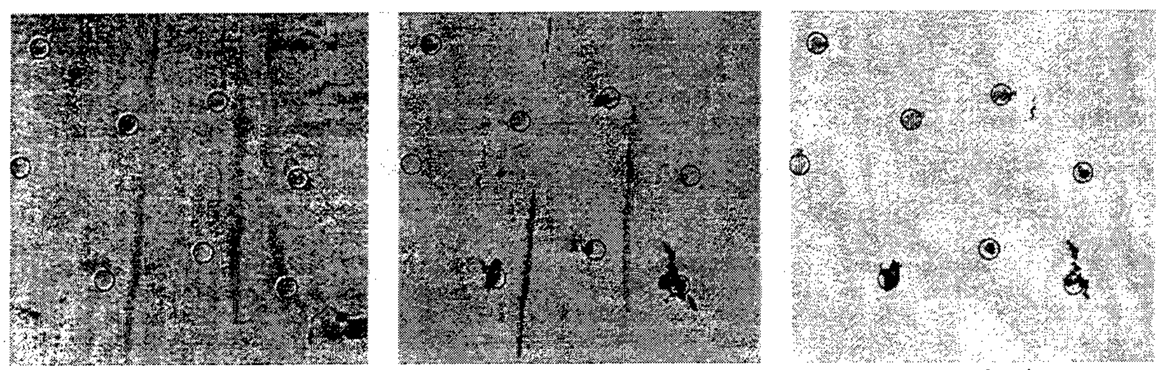
b. SAM results

c. SAM overlaid onto Simulated FLIR

Figure 25. Hyperspectral Results from WESTERN RAINBOW (from Collins, 1996)

1. Mine Detection

Delgrand (1993) successfully detected land mines buried up to 15 cm deep in a variety of environments using thermal IR data collected in the 5.0 and 10.0 μm region of the EM spectrum. Selected results are shown in Figure 26. The circles in each image mark the land mine locations in image c. The additional processing shown in images b and c highlight the differences in soil temperature to the point where the analyst is confident in declaring the circled spots in image c landmines. The same technique could be done with spectral thermal imagery such as SEBASS. There are some suggestions that visible imagery can detect recently disturbed earth as well (Bergman, 1996; Collins, 1996).



a. unprocessed scene b. warm soil c. tagged mines

Figure 26. Buried Land Mine Detection Using Dual Band IR (From Delgrand, 1993)

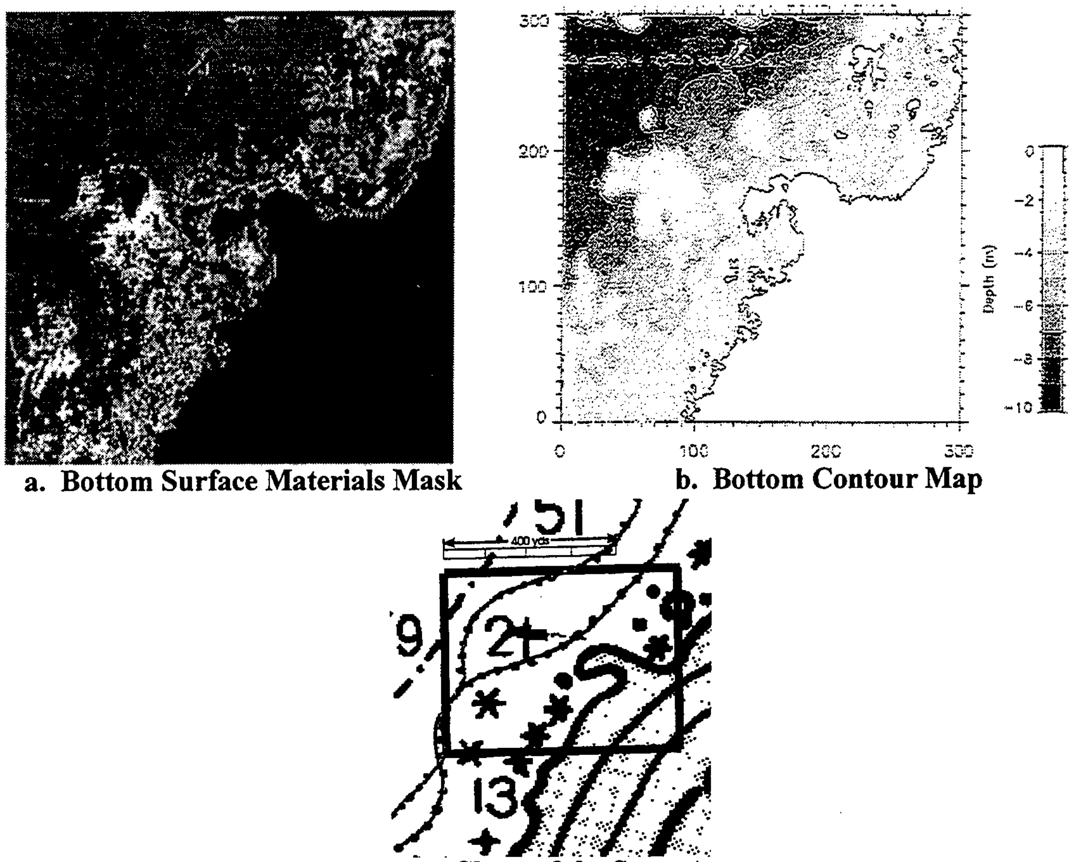
2. Bathymetry

Stuffle (1996) produced bathymetric images out to the 10-meter curve of Secret Harbor, Lake Tahoe, using HYDICE data. Stuffle accomplished this by first producing the "mask" of the water's edge and the bottom materials in the harbor using PCA and

band selection shown in Figure 27.a. Blue indicates sand, yellow indicates bright rock, red indicates dark rock, and black indicates land above water. Then using these known spectra, as well as approximated atmospheric effect and water characteristics, he generated the bottom contour map shown in Figure 27.b using the Bierwirth (1993) Algorithm. These images can provide the planner a significant amount of intelligence when compared to that on a chart of the same area shown in Figure 27.c. The planner now knows what the bottom is made of, the depth of the water in the pertinent areas, and the gradient of the seabed. This intelligence is used to determine where the most desirable points to land are, as well as what areas can damage landing craft. An analyst could not provide any of the intelligence to this level of detail by inspecting any existing format.

3. Target Detection and Identification

Bergman (1996) and Fay (1995) have analyzed HSI data sets in order to determine how effectively military targets could be detected and classified. Bergman (1996) showed it was possible to detect and discriminate between real and decoy vehicles in a natural grass environment, based on the analysis of HSI data from Operation FOREST RADIANCE I. Fay (1995) showed the feasibility in detecting tactical targets in the desert environment based on his analysis of HSI data from Operation DESERT RADIANCE I. The significance in their work is that they show that a properly trained analyst has another method besides ground resolution to detect and classify targets.



a. **Bottom Surface Materials Mask** b. **Bottom Contour Map**

c. **Chart of the Same Area**

Figure 27. Bathymetry of Secret Harbor, Lake Tahoe (From Stuffle, 1996; NOAA, 1987)

This section started by discussing how image analysts should approach HSI exploitation in order to effectively process the data cube. Then some of the information that can be derived from a HSI data cube was presented. This progression now permits the exploration of how HSI can impact amphibious planning.

D. AMPHIBIOUS PLANNING

In warfare, the attacker chooses the point of attack to which the defender must react. Better mission plans take advantage of attackers' capabilities while placing the

defender at the greater disadvantage. Assuming that better quality information at the proper place and time produce a better mission plan, the question the rest of this chapter addresses is, "How does HSI influence the planning process such that the attackers' strengths are optimized while placing the defender at the greatest disadvantage?"

In the largest quantitative sense, this better information allows the attacker to chose the best landing site or point of attack. Better characterization of the battlespace can mean that the attacker is less likely to attack into the heart of the enemy's defense, unless the objective and time constraints demand it. By moving the point of attack away from the defender's strength, the attacker forces the defender to generate combat power at the point of attack in the same manner as the attacker. However, the defenders force must move over land, using a slower rate of advance than the attacker (Gatchel, 1996).

Better characterization of the battlespace has other benefits. First, the planner can accurately estimate what force size is needed to accomplish the mission. In addition, if the analyst is able to detect defenses in a possible landing area that did not previously exist, the planning staff can deal with those contingencies before the execution phase of the operation. For example, if land or seaborne mines are detected near the operation using HSI, the planning staff can plan to sweep, detonate, or maneuver around the minefield. All these options place the defender at a greater disadvantage, because they must now compensate for the failure of these defenses during combat.

Another option the attacker has regards the precision of his attack. If the analyst can more accurately characterize the area of operations by discriminating between decoy and real sites, the attacker's force can be more efficiently employed because decoy sites

are ignored. Similarly, should the analyst be able to discriminate between targets such T-72 and T-80 tanks as Collins (1996) did, this allows the attacker to apply the proper amount of force to achieve a desired effect without wasting valuable munitions. Once again, the defender is placed at a disadvantage, because the attacker has not over-committed his strength to any particular target.

VIII. CONCLUSION / RECOMMENDATIONS

In conclusion, this thesis argues that specialized knowledge in remote sensing and intelligence allows the analyst to establish perceptual constancy and develop the context required to apply knowledge not found in the stimuli to visual information processing. Furthermore, if the analyst is provided specialized knowledge about hyperspectral, he or she can produce additional intelligence that would otherwise that be unattainable, which results in the planner having better knowledge about the operating area from which to produce a mission plan from.

Images derived from hyperspectral sensors are imagery intelligence. This format should be integrated as an operational capability as soon as possible. Hyperspectral sensors could be deployed with tactical forces in a manner similar to the F-14 Tactical Aviation Reconnaissance Pod System (TARPS). However, until image analysts are properly trained and can explain the results of their work to a mission planner, HSI will not gain widespread acceptance because of the complicated nature of the displayed results. In addition, further work in the areas of intelligence architecture and systems must be addressed to maximize the benefits of spectral imagery exploitation. HSI is another format that the analyst should have at his disposal to ensure the battlespace is properly described, so that the planner can create the mission that best meets the prescribed objectives.

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APPENDIX A: COLOR FIGURES

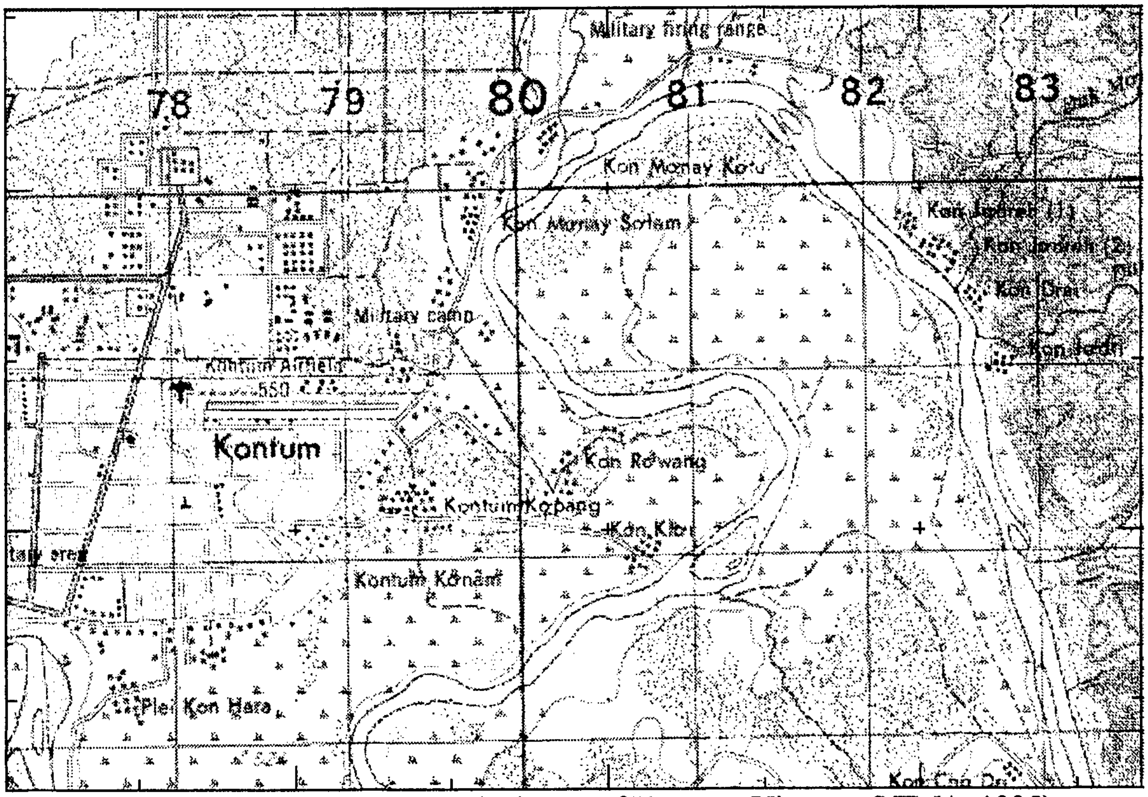


Figure 2. 1:50,000 Topographical Map of Kontum, Vietnam (NIMA, 1995)

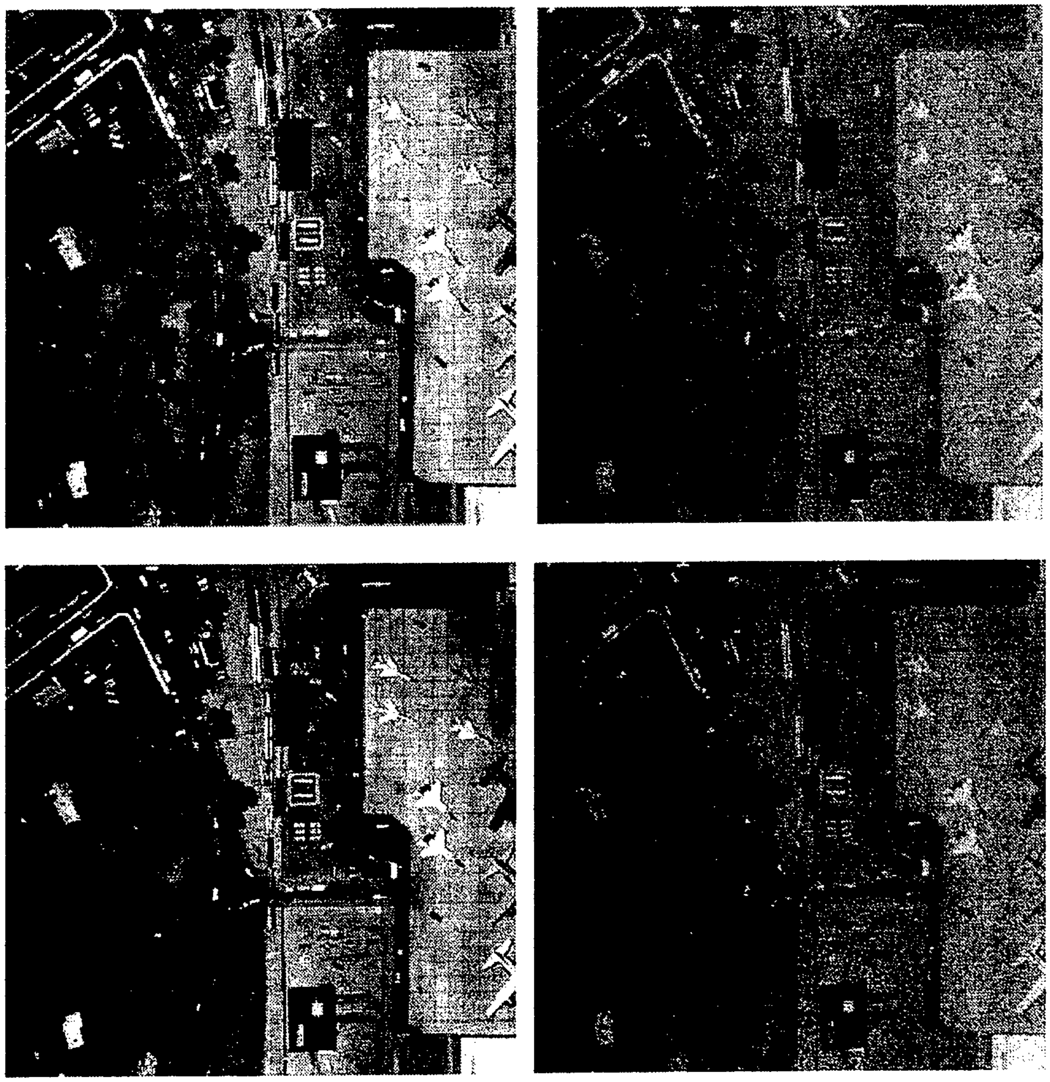
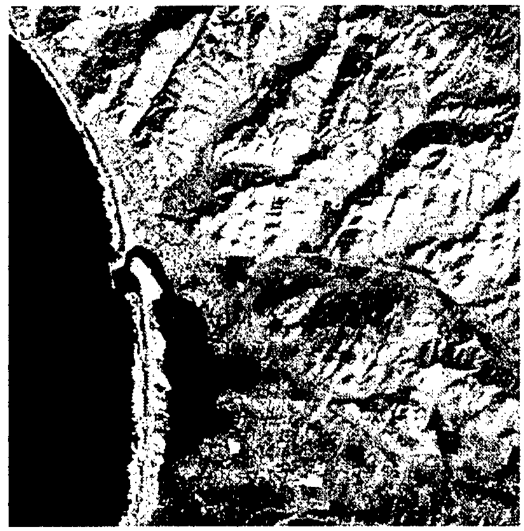
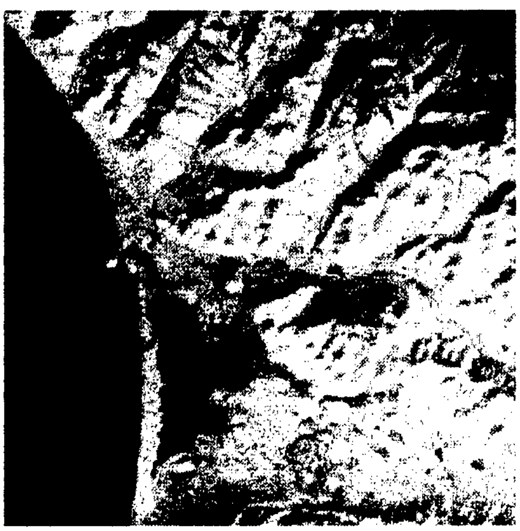


Figure 8. Images with Identical GSD and Varying Image Quality (IRARS, 1995)

a. True Color Bands 1, 2, 3 (BGR)



b. NIR False Color TM Bands 2, 3, 4 (BGR)



c. False Color TM Bands 5, 7, 6 (BGR)

d. False Color TM Bands 4, 7, 1 (BGR)

Figure 14. True and False Color Composite Images of Morro Bay, CA (Short, 1999)

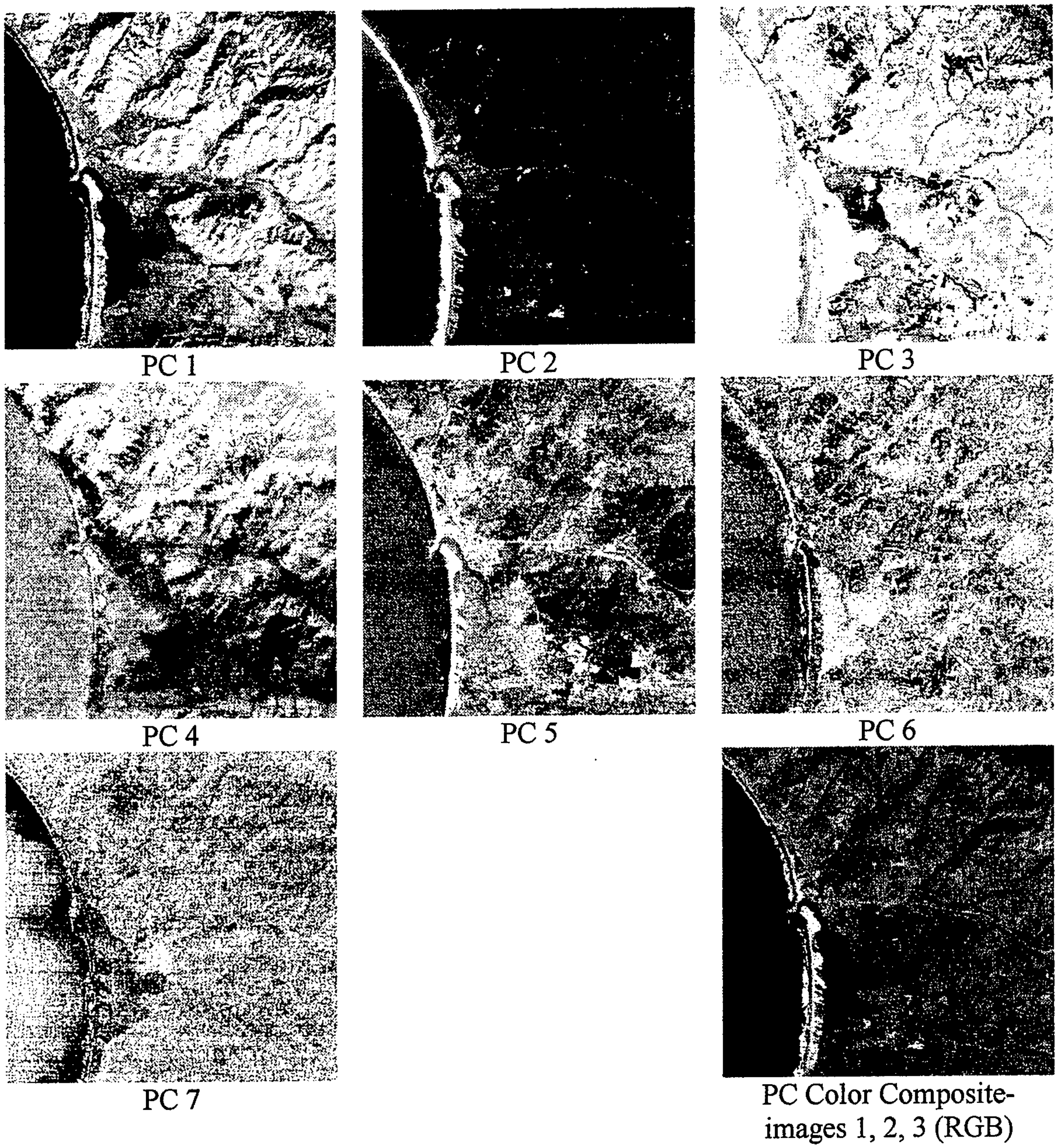


Figure 15. PC Component Images of Morro Bay, CA (Short, 1999)

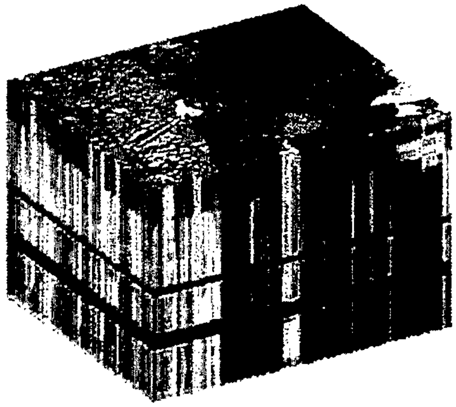


Figure 16. Sample Hyperspectral Data Cube (From Short, 1999)

Figure 17. True Color Composite of Eglin AFB (Thanks to Chris Simi, Night Vision Lab)

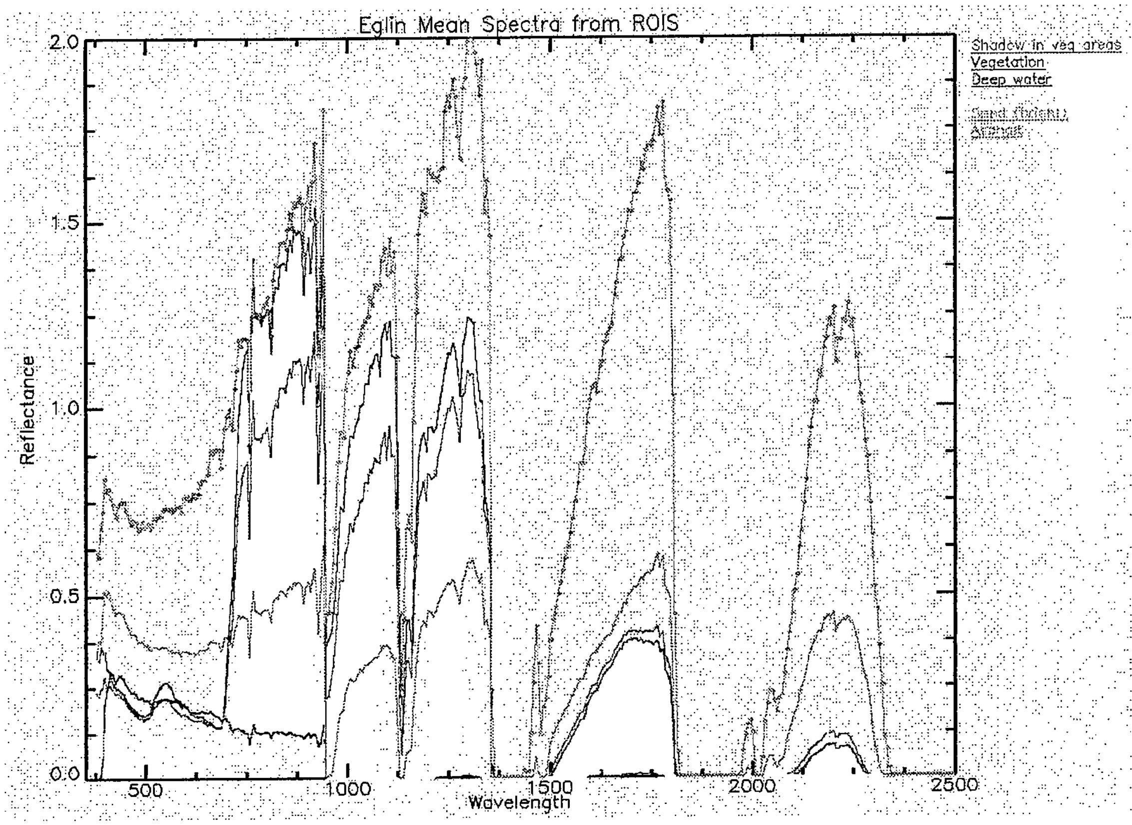


Figure 18. Mean Spectra for Regions of Interest

Figure 19. Regions of Interest for Classification Overlaid on PC 2

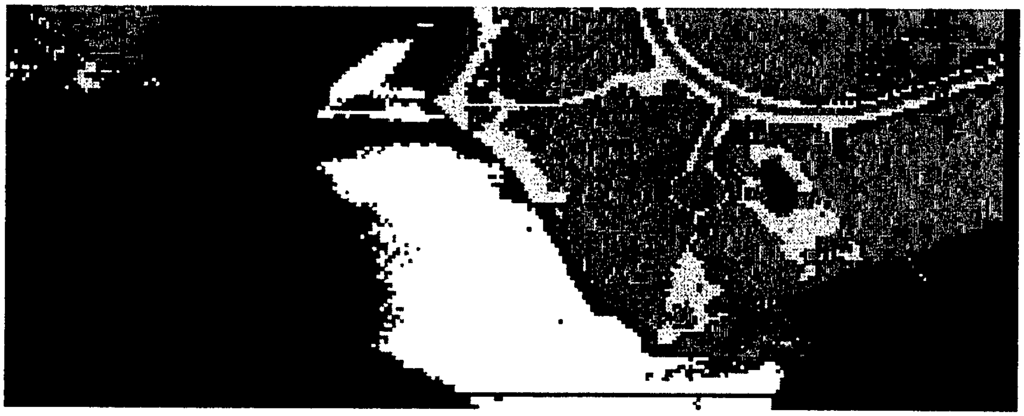


Figure 20. Target Map of Eglin AFB Produced by SAM

Figure22. SMF Color Composite with Selected SAM Data Overlaid

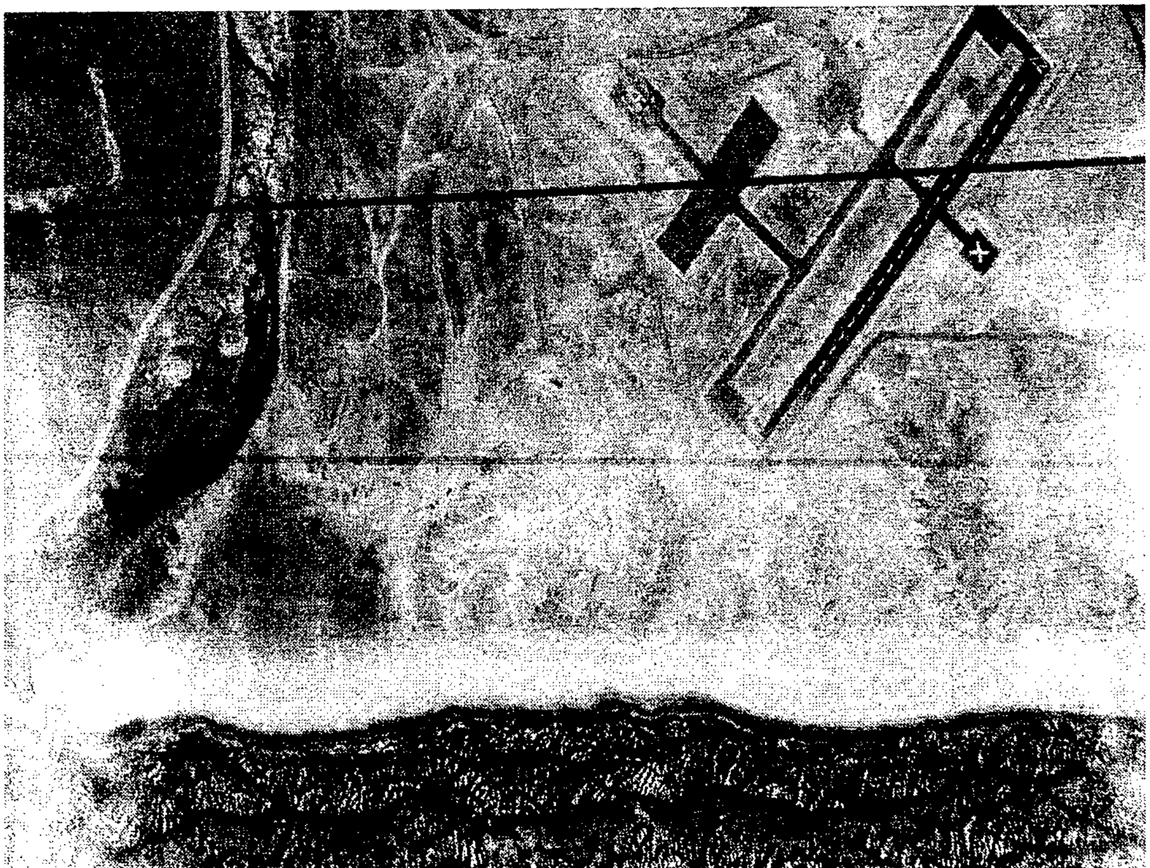
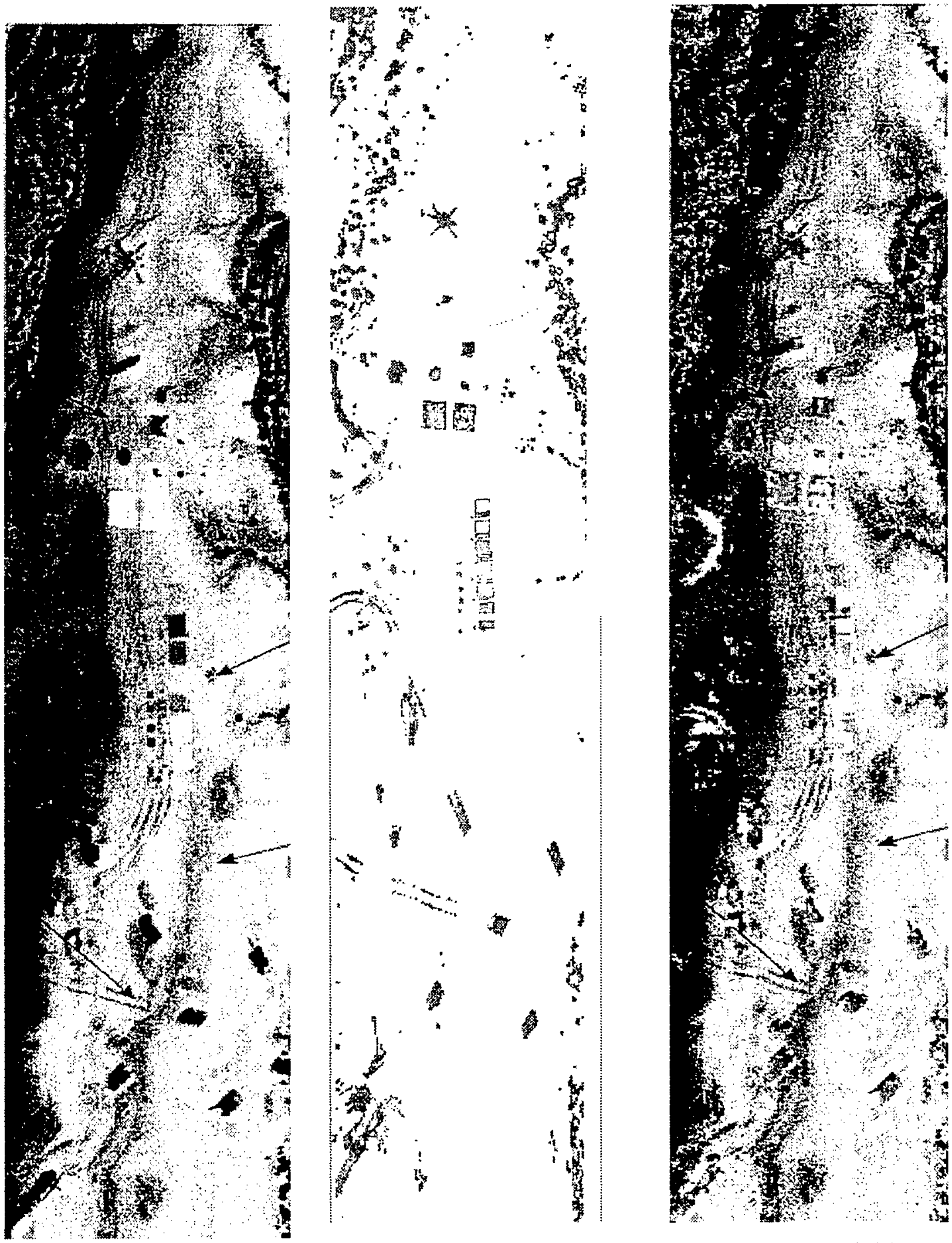
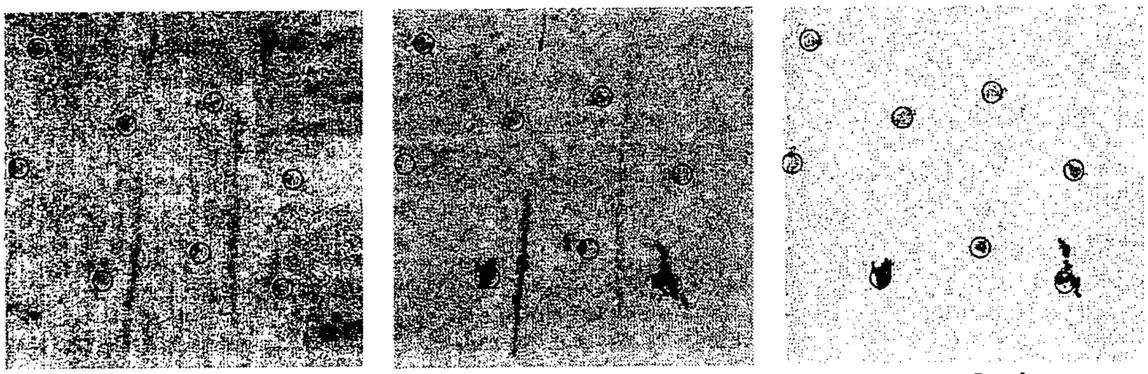


Figure 24. Terrain Categorization of KERNEL BLITZ 1997 Data (SITAC, 1997)



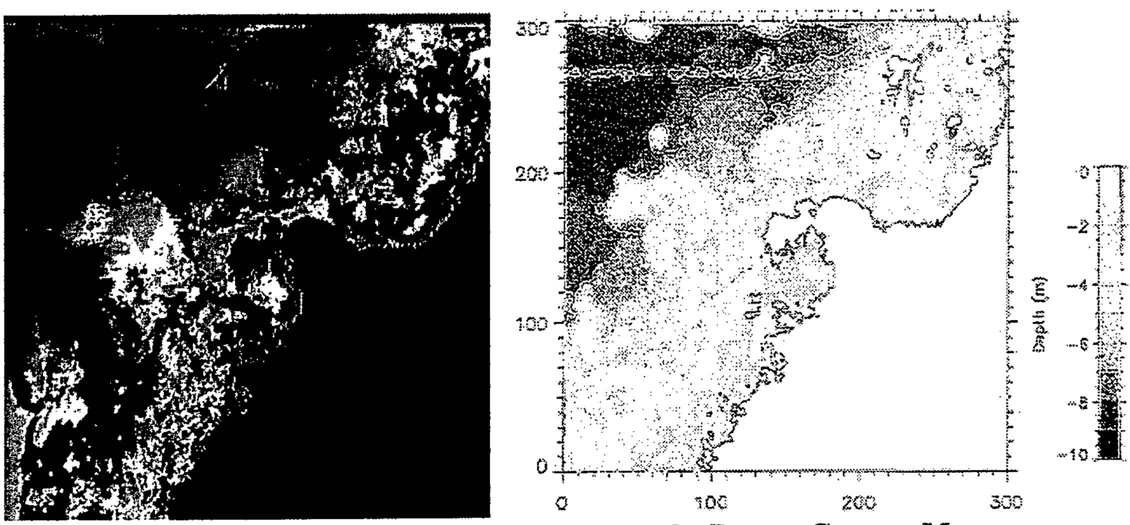
a. Simulated FLIR b. SAM results c. SAM overlaid onto Simulated FLIR

Figure 25. Hyperspectral Results from WESTERN RAINBOW (from Collins, 1996)

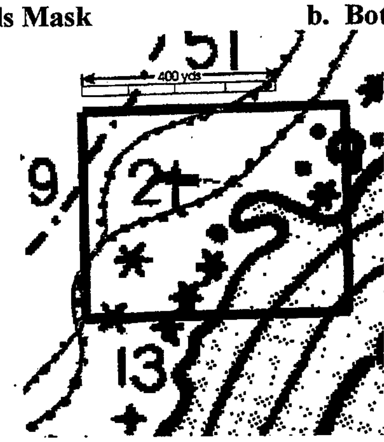


a. unprocessed scene **b. warm soil** **c. tagged mines**

Figure 26. Buried Land Mine Detection Using Dual Band IR (From Delgrand, 1993)



a. Bottom Surface Materials Mask **b. Bottom Contour Map**



c. Chart of the Same Area

Figure 27. Bathymetry of Secret Harbor, Lake Tahoe (From Stuffle, 1996; NOAA, 1987)

APPENDIX B: TASK ELEMENT LIST

A. Determine the general topographic description for the area in question

1. Determine coastal configuration
2. Determine egress routes of coastal areas
3. Identify key terrain in the area
4. Obstacle identification
5. Determine the extent that the terrain provides cover and concealment
6. Determine surface characteristics: slope, materials, and drainage
7. Determine mobility corridors
8. Determine avenues of approach: ground and air forces
9. Determine how this terrain description affects supporting arms

B. Determine the general hydrographic characteristics for the area in question

1. Average Sea-State Determination
2. Determine the underwater gradient for the landing site from the waters edge to the 3-fathom curve
3. Determine the nature of the surf IVO the beach
4. Determine the tidal conditions
5. Determine wind conditions
6. Determine water currents: type, direction and speed
7. Determine existence and location of underwater obstacles

C. Determine the general climatic characteristics for the area in question

D. Determine the nature and extent of transportation facilities in the area

1. Determine characteristics of road network
2. Determine characteristics of the existing rail network:
3. Determine characteristics of inland waterways
4. Determine the availability and condition of existing civil / military telecommunications network

E. Determine enemy military situation

1. Static Orders of Battle
2. Mobile Orders of Battle

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